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ARCHIE RAY CLEMINS
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THESIS

Submitted in partial fulfillment of the requirements
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CHAPTER 1

INTRODUCTION

Under government contract DA-49-129-ENG-542, Arthur D. Little, Inc., developed a digital computer program which was capable of simulating the performances of the electrical components involved in the power plants of anti-ballistic missile (ABM) sites.[1] When subjected to various disturbances, the ABM power plant components must meet very high performance standards; consequently, to accurately simulate the power plant, computer models not ordinarily used in the design and analysis of power plants were developed for some of the various components. Since the original computer program was developed, the design of the power plant has been changed requiring modification of the computer program. This work discusses the modification of the computer program, instructions for using the program, and use of the program in simulating a given power plant configuration.

In order to reduce the repetition of information, and for the sake of brevity, all symbols used in this paper are defined in Appendix A. The reader will find it helpful to scan the appendices prior to reading the text of this paper in order to get a general idea of the information contained therein.

CHAPTER 2

DESCRIPTION OF THE POWER PLANT

The computer program has been modified to be capable of simulating an electric power plant which consists of the following: 6 generators; 9 motor generator (MG) sets, the motors of which are synchronous motors; 4 induction motors which are started directly from the main bus; 16 distribution transformers; a commercial power source which supplies power to the power plant from a distant point through a transmission line and a commercial power interconnection transformer; and a passive RL load connected to the main bus. The MG sets supply RL loads either individually or in parallel pairs. Three of the MG sets are capable of supplying high voltage power supplies which are represented as RL loads. Figure 1 is a one-line schematic diagram of the power plant.

All of the synchronous and induction machines, transformers, and RL loads are three-phase components, and are all balanced except for the RL load connected directly to the main bus which may be either balanced or unbalanced. All RL loads are Y-connected with the neutral grounded. The stators of the synchronous machines and induction motors are Y-connected with the neutral solidly grounded for induction motors, and either solidly grounded or through a reactance for synchronous machines. The commercial power source is Y-connected with the neutral grounded. The primary windings of the distribution transformers and of the commercial power interconnection transformer are Δ-connected while the secondary windings are Y-connected with the neutral grounded.

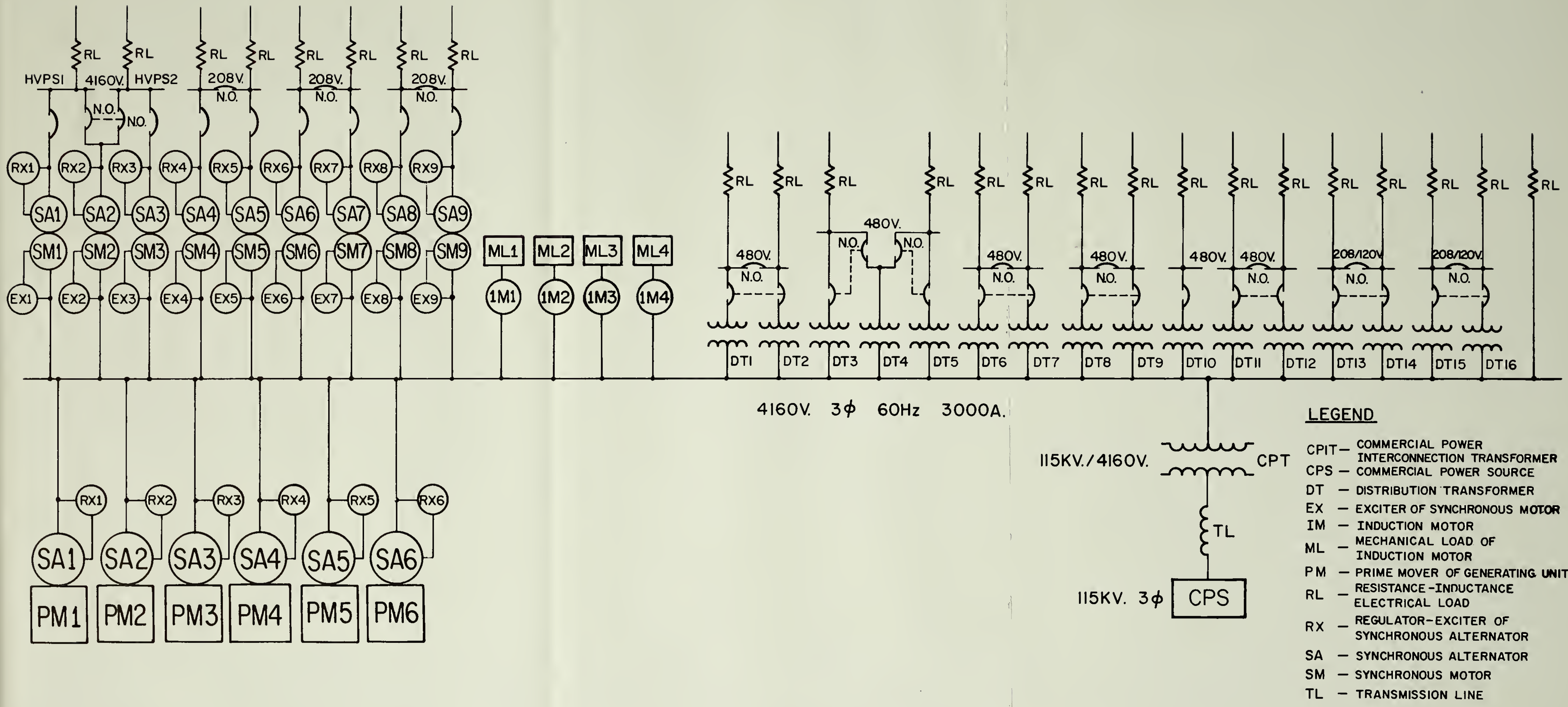

Figure 1. Schematic Diagram of Power Plant

CHAPTER 3

MODELS USED TO REPRESENT THE INDIVIDUAL COMPONENTS OF THE POWER PLANT

3.1 Synchronous Machines

Figures 2 and 3 depict the models that are utilized in the computer program to represent synchronous machines in the direct and quadrature axis. The models take into consideration the fact that the three windings (abc) of a synchronous machine have been transformed by the DQO transformation to three DQO windings.[2] Whereas, the real abc stator windings rotate with respect to the rotor, the fictitious DQO windings are stationary with respect to the rotor. The model contains 14 parameters — 10 inductances L_a, L_{sa}, M_{ab}, M_{af}, M_{ad}, M_{aq}, L_f, M_{fd}, L_d, and L_q and 4 resistances R_a, R_f, R_d, and R_q.

Synchronous machines are usually described analytically in terms of standard conventional parameters which are 11 inductances L_D, L_Q, L_{D1}, L_{Q1}, L_{f1}, L_{d1}, L_{q1}, L'_D, L''_D, L''_Q, and L_0 and 6 time constants T'_{fo}, T''_{do}, T''_{qo}, T'_{fs}, T''_{ds}, and T''_{qs}. The equations which relate the conventional parameters to the parameters of the model are

$$L_{sa} = \frac{L_D - L_Q}{3} \tag{3.1}$$

$$L_a = \frac{L_D + L_Q + L_0}{3} \tag{3.2}$$

$$M_{ab} = \frac{L_a - L_0}{2} \tag{3.3}$$

$$M_{af} = \frac{\text{slope of air gap line}}{\omega} \tag{3.4}$$

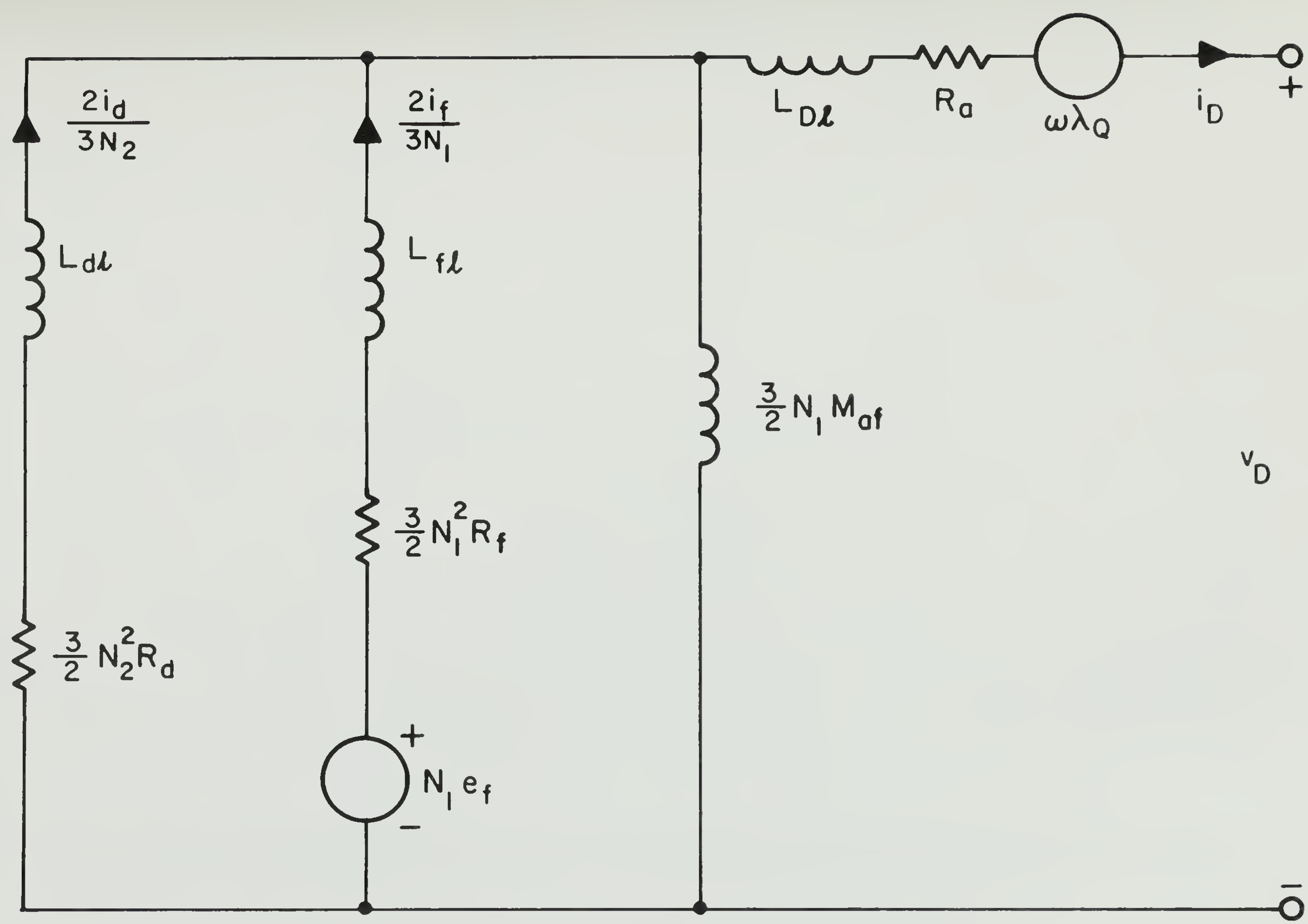

Figure 2. Equivalent Circuit for Synchronous Machines in the Direct Axis

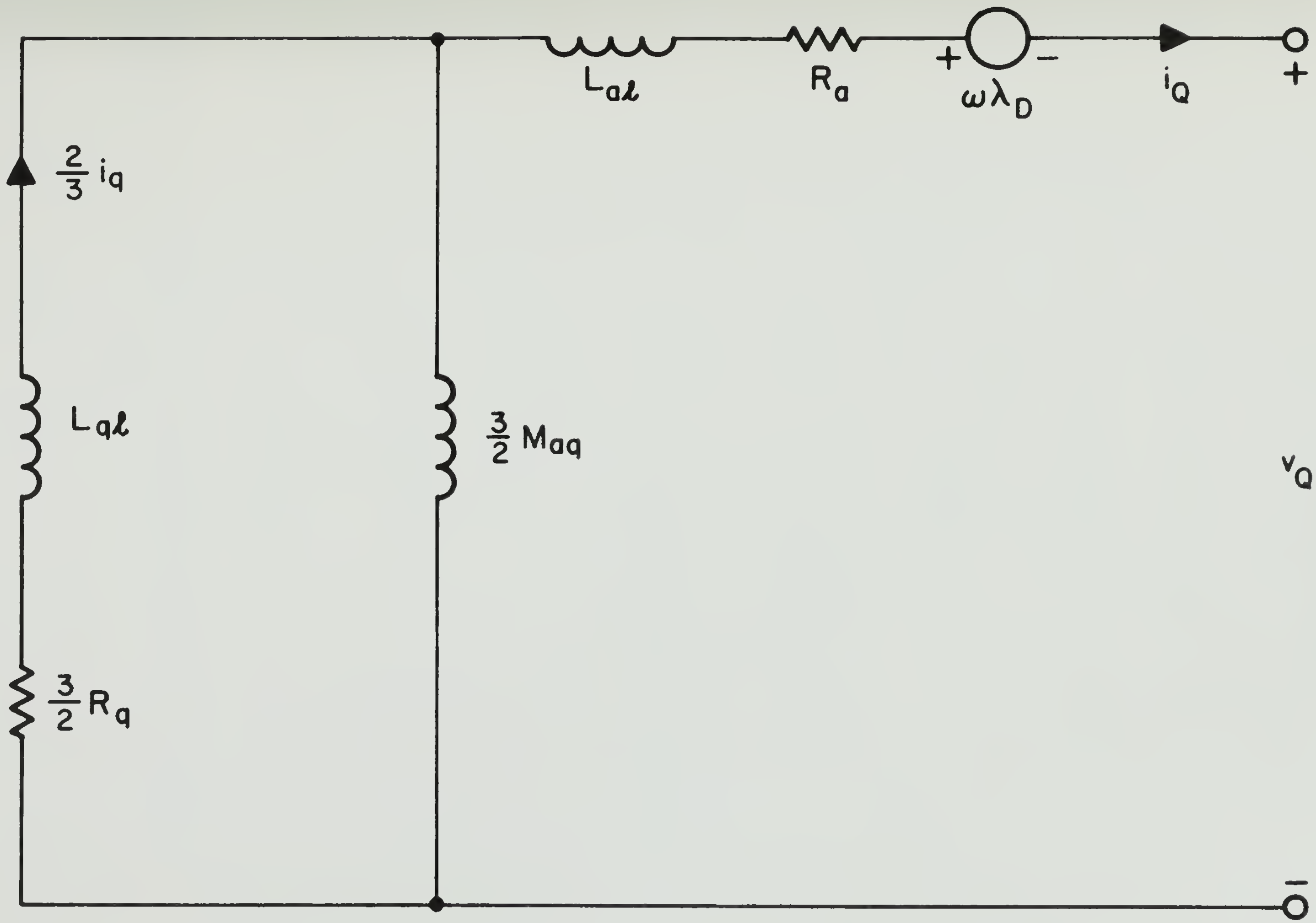

Figure 3. Equivalent Circuit for Synchronous Machines in the Quadrature Axis

$$M_{fd} = \text{specify arbitrarily} \tag{3.5}$$

$$M_{ad} = \frac{(.66)(L_D - L_{D1})M_{fd}}{M_{af}} \tag{3.6}$$

$$M_{aq} = (.66)(L_Q - L_{Q1}) \tag{3.7}$$

$$L_f = \frac{(1.5)M_{af}^{\;2}}{L_D - L'_D} \tag{3.8}$$

$$L_q = \frac{(1.5)M_{aq}^{\;2}}{L_Q - L''_Q} \tag{3.9}$$

$$L_d = \frac{L_{d1} + (1.5)(M_{ad}/M_{fd})M_{af}}{(1.5)(M_{af}/M_{fd})^2} \tag{3.10}$$

$$R_d = \frac{(.66)}{(M_{af}/M_{fd})^2 T''_{do}}\left(L_{d1} + \frac{M_{af}L_{f1}M_{fd}}{M_{ad}L_f}\right) \tag{3.11}$$

$$R_q = \frac{L_q}{T''_{qo}} \tag{3.12}$$

$$T''_{do} = \frac{L'_D}{L''_D} T''_{ds} \tag{3.13}$$

$$T_{qo} = \frac{L_Q}{L''_Q} T''_{qs} \; . \tag{3.14}$$

Equations (3.13) and (3.14) are useful only if T''_{ds} and T''_{qs} vice T''_{do} and T''_{qo} are specified.

In order to obtain C and λ_s, the open-circuit saturation curve must be utilized. On the open-circuit saturation curve, determine the current i_f where saturation just begins; then using this current,

obtain λ_s from

$$\lambda_s = L_f i_f . \tag{3.15}$$

Next, choose a point such that the corresponding voltage lies above the saturation point of the curve. The difference between the field current, i_f, required to give this voltage utilizing the open-circuit saturation curve and the current required using the air-gap line is i_s. Therefore,

$$\lambda_f = L_f(i_f - i_s) \tag{3.16}$$

$$C = \frac{i_s}{(\lambda_f - \lambda_s)^2} . \tag{3.17}$$

In summary, the parameters of the model can be determined uniquely from the specification of (a) the conventional parameters L_D, L_Q, L_O, L_{D1}, L_{Q1}, L'_D, L''_D, L''_Q, T''_{do}, or T''_{ds}, and T''_{qo} or T''_{qs}; (b) the open-circuit saturation characteristics of the machine; (c) the stator resistance R_a and the field resistance R_f; and (d) M_{fd} which may be specified arbitrarily.

3.2 Induction Motors

The induction motor is represented by a 5 abc$\alpha\beta$ winding model which contains 6 parameters — 4 inductances L_a, L_α, M_{ab}, and $M_{a\alpha}$ and 2 resistances R_a and $R_{a'}$. The model parameters can be determined from conventional parameters which are usually defined in terms of a transformer equivalent circuit such as is shown in Figure 4. The transformer equivalent circuit in Figure 4 is for a 5 abc$\alpha\beta$ winding model, whereas standard

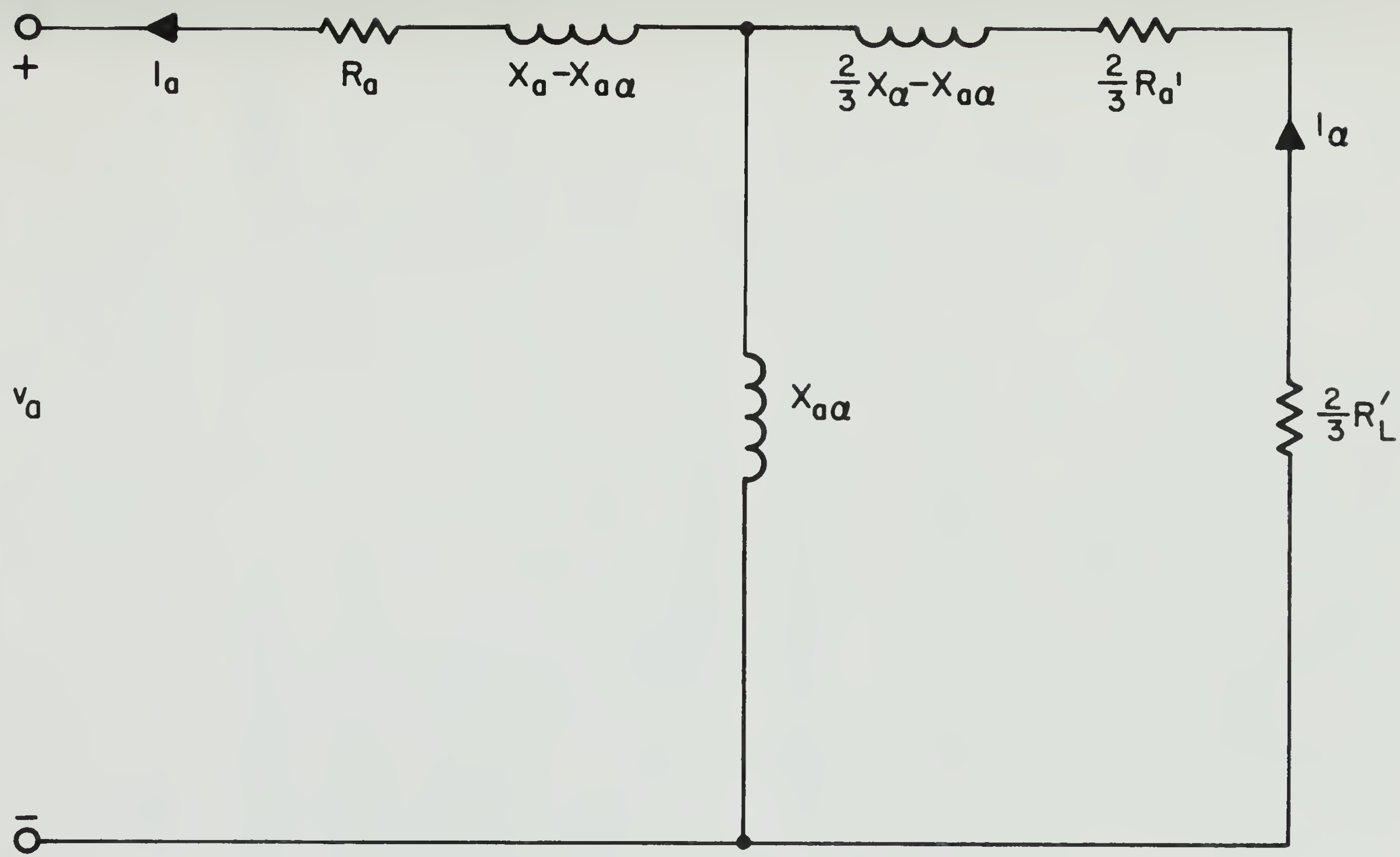

Figure 4. Transformer Equivalent for Phase-a of an Induction Motor with Two αβ Rotor Windings

conventional parameters are defined by a 6 abca'b'c' winding transformer equivalent circuit. The conventional parameters given by the 6 winding transformer equivalent circuit are $X_{a'\ell}$, X_{aa}, $X_{aa'}$, R_a, and $R_{a'}$. Using the standard conventional parameter plus L_0, the model parameters can be determined using the following equations:

$$M_{aa}' = \frac{(.66)X_{aa'}}{\omega} \tag{3.18}$$

$$M_{ab} = \frac{X_{a\ell}/\omega + (1.5)M_{aa'} - L_0}{3} \tag{3.19}$$

$$L_a = \frac{X_{a\ell}}{\omega} + (1.5)M_{aa'} - M_{ab} \tag{3.20}$$

$$L = \frac{X_{a'\ell}}{\omega} + (1.5)M_{aa'} \tag{3.21}$$

$$M_a = \left(\frac{\sqrt{3}}{2}\right)M_{aa'} . \tag{3.22}$$

The total moment of inertia of the motor and its mechanical load and the number of pole-pairs of the induction motor are also needed for the computer program to completely simulate the induction motor.

3.3 Regulator-Exciter System for Synchronous Alternators and Synchronous Motors

Only a brief description of the regulator and exciter system used for synchronous alternators and synchronous motors will be presented here. The purpose of this section is to sufficiently familiarize the user of the computer program with the regulator-exciter system so that the parameters needed for the program can be determined.

The model for the regulator-exciter system of synchronous alternators is shown in Figure 5. The model represents a system with conventional regulating features and a saturable current potential transformer (SCPT) exciter. The exciter is represented in the model by a current source i_{ff} with a source resistance R_m. The current i_{ff} is determined using the instantaneous terminal phase voltages v_a, v_b, and v_c, and stator currents i_a, i_b, and i_c of the alternator. The source resistance R_m represents the magnetizing impedance of the exciter transformers, and the saturation of these transformers is accounted for in the model by means of a simple limiter.

The voltage regulator is represented in the model by an amplifier, a feedback network, and a limiter. The amplifier is defined by its gain k_3, time delay t_3 and output voltage e_3 which is limited by E_3. The feedback network has a time constant of t_4 and a time delay t_4'.

The terminal-voltage feedback and reactive-load share control features of the model are accounted for by a three-phase, full-wave rectifier and a quadratic filter with gain k_2 and time constants t_2 and t_2'.

To accurately model the system, the parameters needed are E_s, R_m, E_3, k_3, t_3, t_4', t_4, E_{ref}, k_2, t_2', t_2, and k_1. All of these parameters are not usually specified by the manufacturer; therefore, the following method is a suggested way to determine all of the parameters.

E_3 and E_s should be at least 3 to 4 times the field voltage required for open circuit terminal voltage. R_m should be 20 to 30 times the field resistance. k_1 should be chosen so that for a reactive-current error equal to the rated current it produces a 5 percent rated voltage

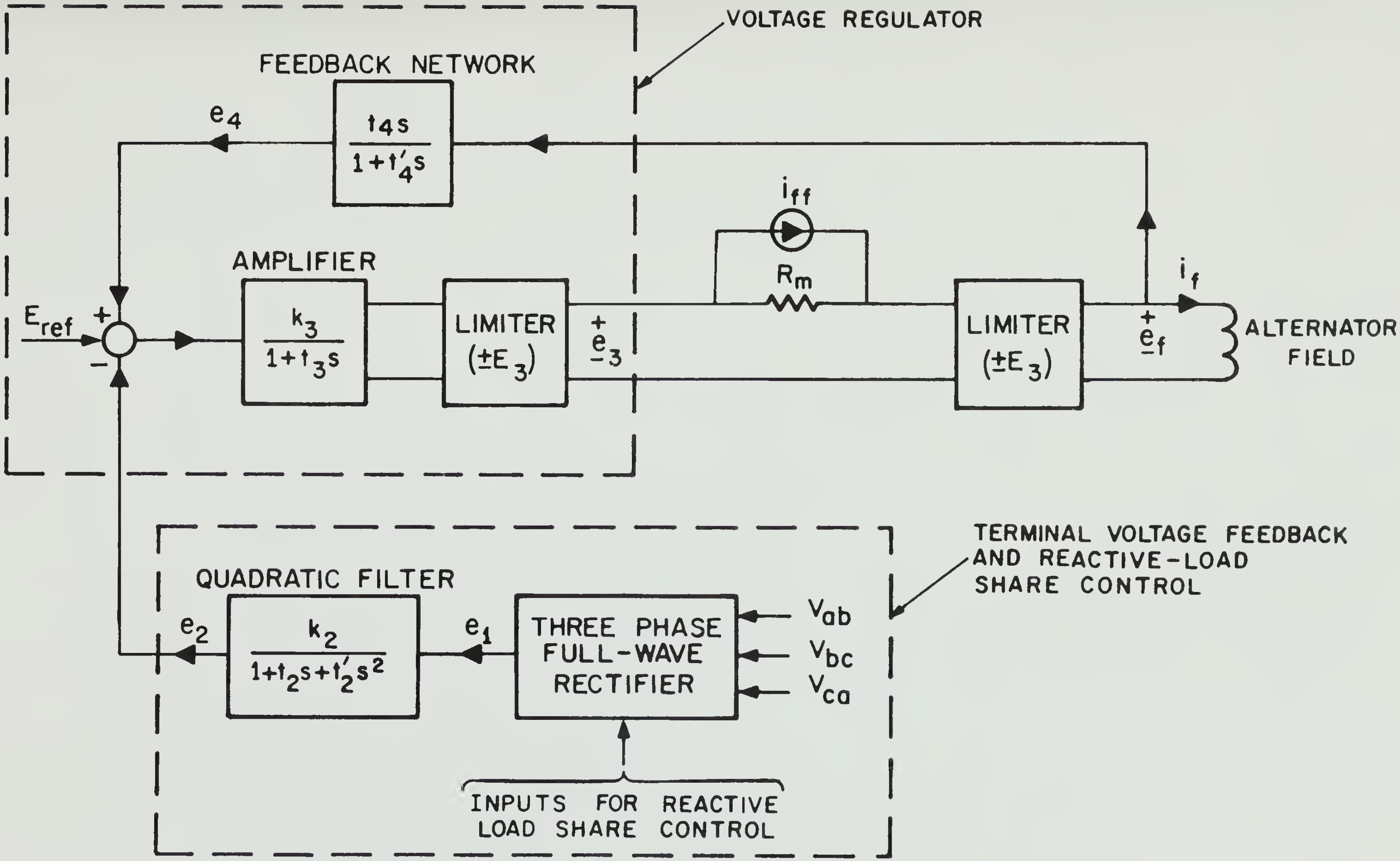

Figure 5. Model for Regulator-Exciter System of Synchronous Alternators

feedback. Once a convenient value for E_{ref} is determined and recovery time for a step load change, T_r, has been specified, the remaining parameters can be obtained from the following equations:

$$t_4' \leq (2/3)\ T_r \tag{3.23}$$

$$t_2' \leq \frac{t_4'^2}{256} \tag{3.24}$$

$$t_3 \leq (0.1) t_4' \tag{3.25}$$

$$t_2 = \sqrt{t_2'} \tag{3.26}$$

$$k_2 = \frac{(\pi) E_{ref}}{3V_{\ell\ell}} \tag{3.27}$$

$$t_{ef} = \frac{L_f}{R_f \sqrt{2}} \text{ (at full load)} \tag{3.28}$$

$$t_{ef} = \frac{L_f}{R_f} \qquad \text{(at no load)} \tag{3.29}$$

$$k_3 \geq (10) \frac{t_{ef}}{t_4'} \tag{3.30}$$

$$t_4 = \frac{k_2 \omega M_{af} t_4'^2}{4\ 2\ t_{ef}} . \tag{3.31}$$

The exciter of a synchronous motor is represented by the model in Figure 6. The model consists of a voltage excitation source e_{ex}, a field discharge resistance R_{fd}, two silicon controlled rectifiers SCR1 and SCR2, and a diode D1. The parameters Δf, k, and R_{fd} must be specified. k is related to e_{ex} through the equation

$$e_{ex} = kV_{\ell\ell} . \tag{3.32}$$

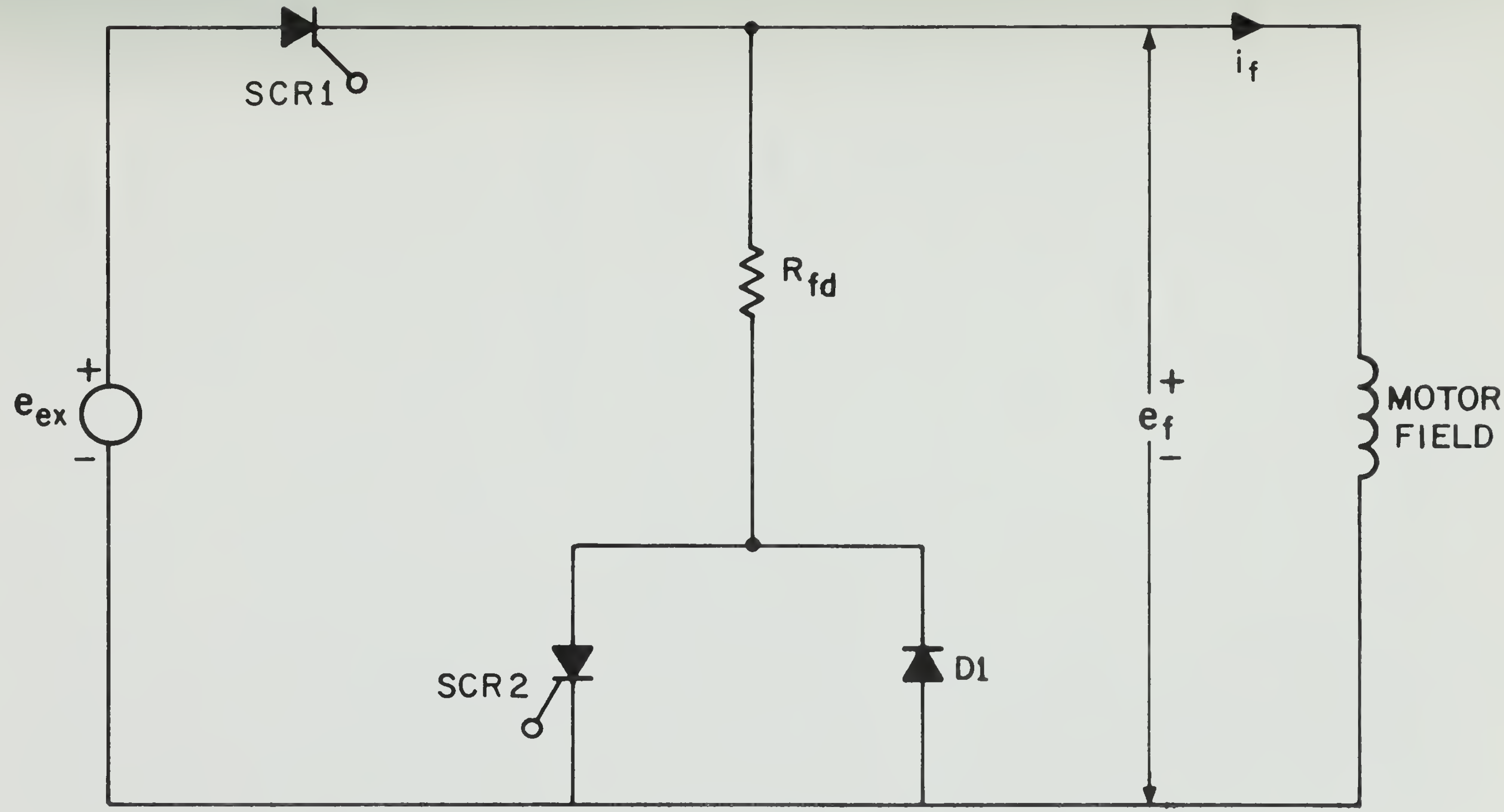

Figure 6. Model for Exciter of Synchronous Motors

3.4 Distribution Transformers

The model used for the distribution transformers is given in Figure 7. As has been previously stated, the primary windings of the transformers are Δ-connected, and the secondary windings are Y-connected with the neutral grounded. The transformers are represented as ideal transformers with a turns ratio, a, equal to that of the actual transformer, plus an equivalent leakage-inductance, L_{eq2}, in series with an equivalent winding resistance, R_{eq2}, per phase. The model does not take into account saturation and magnetizing impedance effects. Each phase of the load is represented by a resistance, R_L, in series with an inductance, L_L. All phases of the load are the same.

The only parameters needed for the model are R_{eq2}, L_{eq2}, and a for the transformer, and R_L and L_L for the load. Each of these parameters can be easily calculated from either the name plate data of the transformer or from readily available load characteristics.

3.5 Commercial Power System

The commercial power system is represented by the model shown in Figure 8. The model represents the following: (1) a three-phase commercial power source with peak phase voltage E_U and the phase angle of phase a being equal to χ, and the source impedance per phase consisting of an inductance, L_U, in series with a resistance, R_U; (2) a three-phase transmission line which is assumed to be balanced and is represented per line by an inductance, L_T, in series with a resistance, R_T; and (3) a commercial power interconnection transformer which is identical to the model for distribution transformers in Section 3.4.

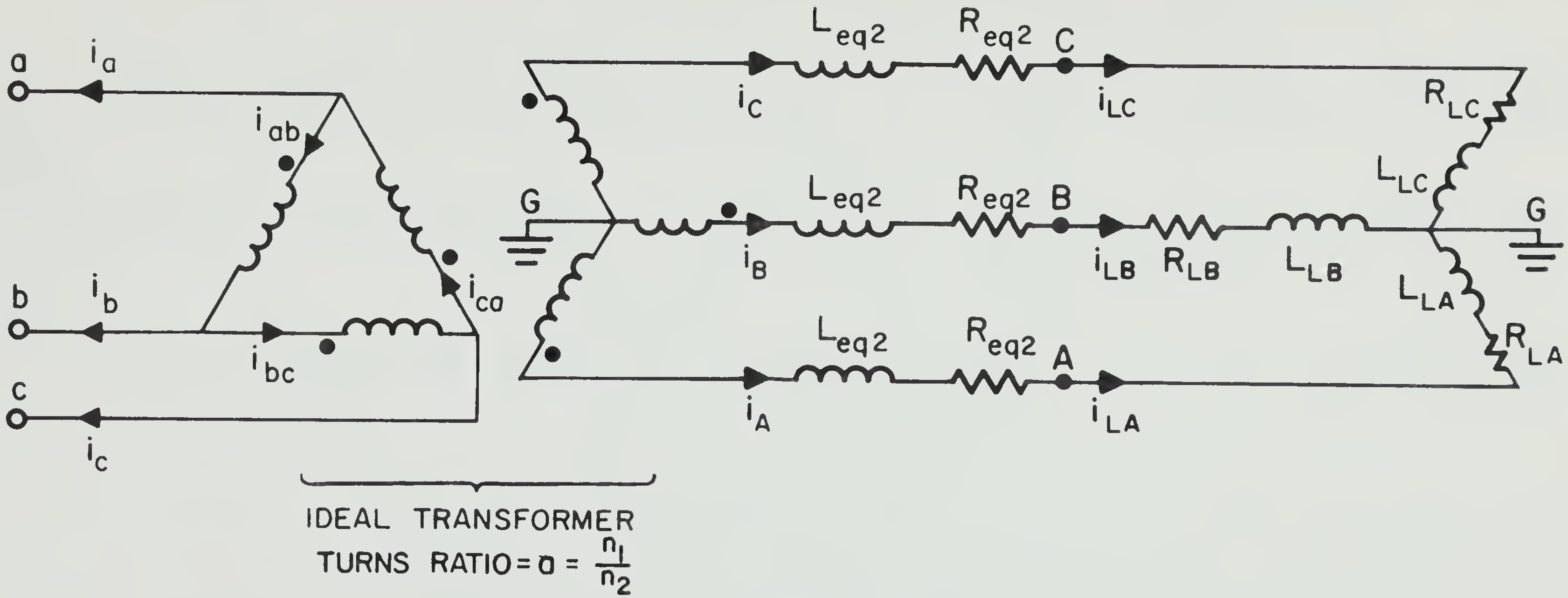

Figure 7. Model for Distribution Transformers and Their Loads

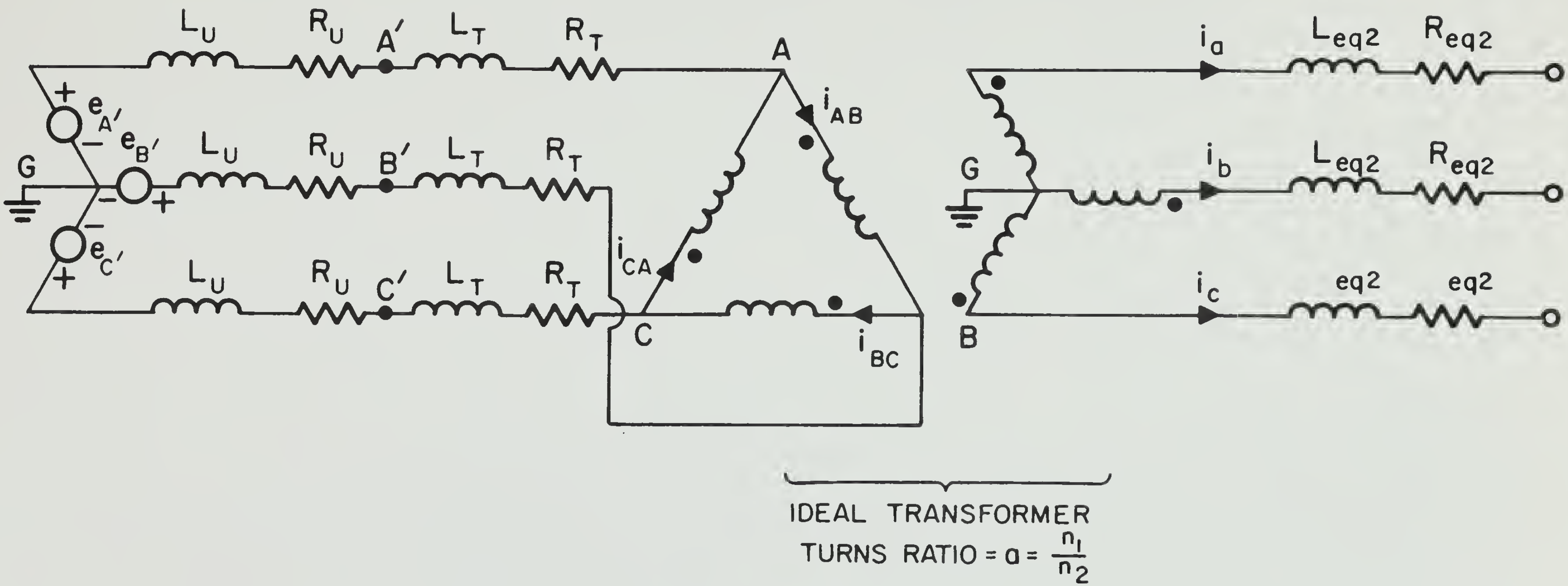

Figure 8. Model for Commercial Power System

The parameters needed for the program to be able to represent the model are L_{eq2}, R_{eq2}, and a for the interconnection transformer; L_{T2} and R_{T2} for the overhead transmission line; and L_{U2}, R_{U2}, and E_{U2} for the power source. L_{T2}, R_{T2}, L_{U2}, R_{U2}, and E_{U2} are equal to L_T, R_T, L_U, R_U, and E_U divided by a^2 and a respectively. All of these parameters are readily available from published data. In addition to the above parameters, the value of χ must also be inserted in the program, and the method of determining its value is described in Section 5.5.

CHAPTER 4

DESCRIPTION OF THE COMPUTER PROGRAM INCLUDING A SUMMARY OF THE CAPABILITIES OF THE PROGRAM

4.1 Design of the Computer Program

Generally a power plant is divided into two subsystems. One subsystem consists of the prime movers of the generating units and their fuel supplies. The second subsystem contains either the rest of the power plant or the portion which contains the electrical components. The computer program which represents the prime movers and their fuel supplies will be called the MAIN program. The computer program which represents the rest of the power plant will be called the SUB2 program. In order to run the SUB2 program, a MAIN program is required. The MAIN program has two principal functions — (1) it serves as the main routine of the overall power plant, and (2) it contains the model for the prime movers of the generating units and their fuel supplies.

The SUB2 program is simply a large subroutine of the MAIN program. It cannot be emphasized enough that the MAIN and SUB2 programs are completely independent. The two programs are linked by the following FORTRAN call statement from the MAIN program; CALL SUB2 (XA, SP, TOR, XLOAD, FR, NS).[3] XA represents time (in seconds), and SP is a one-dimensional array which contains the mechanical speeds (in rad/sec) of the shafts of the generating units. Arrays TOR and XLOAD are one-dimensional arrays that contain the electromagnetic torques (in ft-lb) and the electrical loads (in kW) of the generators of the generating units. FR is the electrical

frequency of the main bus (in Hz), and NS is the number of generating units that remain connected to the main bus at a given instant of time.

The two programs work in the following prescribed manner. When the MAIN program calls SUB2, SP and XA are transferred from MAIN to SUB2. XA should be greater than or equal to SUB2 time X. IF XA is larger than X, SUB2 integrates the differential equations of all the components of SUB2 to time XA using the same speeds SP for the shafts of the generating units throughout the integration. At the end of this integration, SUB2 computes TOR, XLOAD, FR and NS and returns to the MAIN program. The values of TOR, XLOAD, FR and NS transferred to the MAIN program can be used to integrate, in the MAIN program, the differential equations of the prime mover and the fuel control model to a later time XA. Once the integration is completed a new SP and a new time XA can be calculated and the procedure repeated.

It is very important to realize that any MAIN program which is compatible (has similar logic structure) with SUB2 may be used. Two very simple MAIN programs have been included in Appendix C with the SUB2 program. One of them, SPEED, uses constant speed models for the prime movers, and the other one, TORQUE, uses constant developed torque models for the prime movers. Again, both of these MAIN programs are very simple. An actual simulation of a given power plant configuration would require a much more complex model.

4.2 Description of the SUB2 Program

The SUB2 program is based on the models described in Chapter 3. The program is coded in FORTRAN IV. As was mentioned previously, the program for SUB2 is, so to speak, a subroutine of the MAIN program.

In itself, the SUB2 program consists of 50 subroutines. As can be seen by glancing through Appendix C, the first few lines of each subroutine are used to describe the function the subroutine performs. Let it suffice to say that each subroutine performs a special function in the computer simulation, and all the subroutines combine to form the SUB2 program which simulates the whole electrical power plant.

Used in the SUB2 program are several subscripted FORTRAN arrays. These arrays are in common to all of the subroutines with the exception of subroutines SETF and SETI which have no common. The arrays contain the parameters and variables of the various components as well as other variables used by the computer program. Parameters of different components are sometimes placed in the same array. When this is done, various parts of an array are assigned to the various components. For example, in a two-dimensional array a given component is assigned to a given column. The various parts are assigned using the following ordered arrangement: (1) all generators of generating units, (2) all MG sets, (3) all induction motors, (4) all distribution transformers, and (5) commercial power system. Throughout the rest of the paper the above ordered arrangement will be referred to many times.

The arrays used in the SUB2 program are the following: A(80,35), B(99,35),BO(8),CD(3,4),D(120),EG(50),EP(50),F(316),G(21,35),GB(3,4,9), Q(316),VV(21,9),W(6,6,9),X,XL(6,10,35),XM(6,10,9),Y(316),Z(6,6,35),L(134), LG1(50),LG2(50),LG3(50),LP1(50),LP2(50),LP3(50),TITLE(39),HEAD(39).

The dimension of most of the arrays is determined by the maximum number of components in the power plant to be considered. The arrays above require 13,271 computer memory locations. These arrays have been

tailored to accommodate the power plant in Figure 1. The second subscript of all the two-dimensional arrays, except CD(3,4), and the third subscript of all three-dimensional arrays correspond to the position of the respective component in the ordered component arrangement. The elements of the more important arrays are defined in Appendix B. In Appendix B the subscript I corresponds to the position of a component in the ordered arrangement of components; whereas, the subscript J specifies the first entry in the Y array of the dependent variables of a component.
In addition to the information given in Appendix B, array Y contains all the dependent variables of the components; and, array F contains the corresponding first-time derivative of the dependent variables.

4.3 Capabilities of the Computer Program

The computer program is quite versatile. Providing the models given represent the components to be simulated, the only restrictions on the components used in the simulation are as follows:

(1) There must always be an RL load on the main bus;

(2) The total number of generating units, MG sets, induction motors, and distribution transformers does not exceed 35;

(3) The number of generating units does not exceed 6;

(4) The number of MG sets does not exceed 9;

(5) The number of induction motors does not exceed 4; and

(6) Each simulation has at least one power source.

Any power plant with a lesser number of components than specified above may be simulated.

The computer program has many capabilities. Any generating unit, MG set, induction motor or distribution transformer, as well as the

commercial power system, can be disconnected from the main bus at a specified time; however, once a component is disconnected, it must remain disconnected for the remainder of the simulation. Two MG sets may feed the same load in parallel as shown in Figure 1. When one of these generators is disconnected from the common bus, the disconnected MG set idles at no load. All the RL loads in Figure 1 can be varied in two ways. Step changes of a specified magnitude can occur at any time, or the RL loads can be varied sinusoidally with specified frequencies and amplitudes.

Single-phase, two-phase, three-phase, and line-to-line faults can be introduced on the main bus, the buses of MG sets, the secondaries of distribution transformers, and anywhere on the overhead transmission line.[4] The faults can be of any duration. The program can also simulate step changes of a given magnitude as well as pulse changes of a specified magnitude and duration in the voltage of the commercial power source.

Any of the power plant disturbances given above can occur simultaneously during a simulation with the stipulation that only one component can be disconnected at a time.

In addition to the versatility of the program shown above, the computer program calculates the instantaneous values of phase voltages and line-to-line voltages of the main bus, buses of each MG set, and the secondaries of each distribution transformer. The computer program calculates the average three-phase power and the peak reactive power per phase at the terminals of each rotating machine connected to the main bus, the primary and secondary terminals of the commercial power interconnection transformer, and the terminals of each generator of the MG sets. Finally, the computer program calculates the percent error

of the peaks of all the line-to-line voltages and the percent error of the frequencies with respect to 60 Hz. Needless to say, all of the mentioned variables are available for printing or plotting as desired.

CHAPTER 5

OPERATING INSTRUCTIONS FOR THE COMPUTER PROGRAM

5.1 Computer Facilities Required

The program is coded using FORTRAN IV; consequently, the program can be run on any computer which utilizes FORTRAN IV and has sufficient core memory available. The program has been successfully run on both the IBM 360 and CDC 6600 systems. Allowing for the common arrays of SUB2 already described in Section 4.2, the coding of the program for SUB2 listed in Appendix C, along with either the main SPEED or main TORQUE program requires about 32,768 (decimal) units of computer memory.

In addition to the standard input tape 5 and output tape 6 used by all FORTRAN programs, the SUB2 program requires additional tapes 2 and 7. This is an important consideration in the preparation of the control cards for the program. Tape 2 is utilized by subroutine PLOT2 as extra memory where information can be stored in binary form. The information stored in tape 7 is identical to the information printed out by tape 6; consequently, the information stored in tape 7 can be saved and plotted out at a later time.

5.2 Input Information Required

Regardless of the simulation, the following parameters and variables are required for all computer simulations: The initial time X, C(1) to C(15), L(1) to L(7), and L(9) to L(10). Depending on what components are present during a given simulation, the following parameters and variables must be specified

(1) Generators of generating units — A(1,I) to A(17,I), A(20,I) to A(33,I), B(14,I), L(I+99), Y(J) to Y(J+10), and F(J+8);

(2) MG sets — A(1,I) to A(17,I), A(20,I) to A(26,I), A(31,I) to A(46,I), A(49,I) to A(61,I), A(68,I) to A(80,I), B(42,I), L(I+99), Y(J) to Y(J+18), and F(J+16);

(3) Induction motors — A(1,I) to A(10,I), A(11,I) to (depending on the value of A(10,I)), L(I+99), and Y(J) to Y(J+6);

(4) Distribution transformers — A(1,I) to A(12,I), L(I+99), and Y(J) to Y(J+2);

(5) Commercial power system — C(35) to C(48), L(8), and Y(J) to Y(J+2).

One of the iterms required, C(1), is the integrating time step. In the absence of induction motors from the simulation, an integrating step of 1 millisecond should be sufficient. However, due to the fact that induction motors operating at or near full load have very small time constants, the integrating step should probably be reduced to about one-third of a millisecond when induction motors are involved in a simulation.

5.3 Input Format

The MAIN program requires input information which is described in Section 5.6. The data for SUB2 must be placed directly after the data for the MAIN program. When the word deck is referred to in this section, it refers to the data deck for SUB2.

The first three cards of the deck contain the information for the common array TITLE. This information is contained in format 13A6 and is a verbal description of the simulation. The description is printed out at the beginning of the output. The next three cards of the deck contain the information for the common array HEAD. The information HEAD is also a verbal description contained in format 13A6. HEAD provides a method for explaining the information contained per record

in the outputs of subroutine TAPE2. The verbal description in HEAD appears in the outputs produced by TAPE2 right after TITLE.

Following the first 6 cards of the deck are cards which can be of three general categories. Each category is characterized by one of the three letters I, P, or G which is punched in the first column of the card. The I-cards contain the input information of Section 5.2 which goes into the common arrays X, Y, F, L, C, D. A, and B. The P-cards contain instructions for the output subroutine PRINT2. The G-cards contain instructions for subroutine PLOT2. The I-, P-, and G-cards can appear in any order in the data deck; however, the P- and G-cards are executed by PRINT2 and PLOT2 in the order they appear. The most logical order would be to group the P-cards and G-cards into separate groups and to place them in the data deck in that order.

Let us first consider the I-cards. The format for the I-cards can be either for the one-dimensional arrays X, Y, F, L, C, and D, or for the two-dimensional arrays A and B. For the one-dimensional arrays, the format of an I-card is A1,1X,A1,I3,1X,I3,6E10.4. The first alphanumerical character of an I-card is I. The second alphanumerical character identifies the array whose values are contained on the card. The two integers contained on the card specify the lower and upper values of the subscript of the array whose values are contained on the card. The values of the array follow the second integer. For example, consider an I-card which has the second alphanumerical character equal to C and the first and second integers are 1 and 6; then, the card contains the values of C(1) through C(6).

The format of an I-card for the two-dimensional array A or B is A1,1X,A1,I2,I2,1X,I2,6E10.4. The first integer specifies the value of the second subscript of the array A or B. The second and third

integers specify the lower and upper values of the first subscript of the array A or B whose values are contained on the card. The alphanumerical characters have the same significance as before. Consider the example in which the three integers are 7, 10, and 15, and the second alphanumerical character is A; then, the I-card contains the values for A(10,7) through A(15,7).

The P-cards contain the information which tells subroutine PRINT2 the values of the common arrays to be printed out. For the one-dimensional arrays, the format of the P-cards is A1,1X,A1,I3,1X,I3. For the two-dimensional arrays, the format is A1,1X,A1,I2,I2,1X,I2. The meaning of the information punched on the P-card is similar to that punched on the first 10 columns of the I-card. For example, consider the P-card that has the two alphanumerical characters P and B and the three integers 3, 5, and 22; then, the values of B(5,3) through B(22,3) will be printed out by subroutine PRINT2.

The G-cards perform the same function for subroutine PLOT2 that the P-cards perform for subroutine PRINT2; the format is exactly the same as that of the P-cards.

The last card of the data deck must be a card with the letter R in the first column and the rest of the columns blank. This card informs the program that all the data cards have been read in. It is important to remember, as stated earlier, that in addition to the data deck, described in detail above, the data deck for the MAIN program must precede it.

Any number of I-cards may be used to insert the input data into the program. Due to the size of the arrays EP, LP1, LP2, LP3, EG, LG1, LG2, and LG3, which contain instructions for subroutines PRINT2 and PLOT2,

only 50 P- or G-cards may be present for a given simulation.

5.4 Output Available

The parameters that the SUB2 program calculates were given in Section 4.3. All of these parameters calculated by the SUB2 program are stored in the common arrays and can be obtained as output by using the P- and G-cards. The exact location of a particular parameter can be determined by utilizing Appendix B. However, it is important to realize that subroutine PRINTO produces a printout at the end of each simulation which gives the values of the dependent variables and a few other variables of SUB2 that must be specified in the initial conditions of a simulation. For the initial simulation, approximate initial conditions can be calculated by the method described in the following section. By conducting a steady-state simulation and then obtaining the output from PRINTO, accurate initial conditions are available for subsequent simulations.

5.5 Method of Obtaining Initial Conditions

By conducting a steady-state simulation based on approximate initial conditions and then obtaining the output produced by PRINTO, as explained in the preceding section, accurate initial conditions are available for subsequent simulations. This section describes the method for obtaining the approximate initial conditions for the first run. The procedure below provides the initial conditions for all components connected to the main bus including generators of generating units, motors of MG sets, induction motors, distribution transformers, and the commercial power system. The generators of the MG sets are not described; however, the

initial conditions for these components can be obtained using the same method used for the generators of generating units. The various buses of the MG sets do not have to be in synchronism.

The power plant is assumed to be balanced. Given the voltage of the main bus along with the power and power factor of a component, one can readily calculate the maximum amplitude, I, of the phase currents from the component to the main bus. Assuming time equal to zero is when the phase-a voltage of the main bus is maximum and abc phase sequence, the instantaneous phase currents are

$$i_a = I \cos\phi \tag{5.1}$$

$$i_b = I \cos(\phi + \frac{2\pi}{3}) \tag{5.2}$$

$$i_c = I \cos(\phi - \frac{2\pi}{3}) \ . \tag{5.3}$$

This procedure provides values for the instantaneous phase currents of generators of generating units, motors of MG sets, induction motors, and the commercial power system. For the generator of a generating unit, i_d and i_q equal zero. The remaining parameters needed for the generator are calculated using the following procedure:

(1) θ_o from

$$\theta_o = \tan^{-1}\left(\frac{V + IX_Q\sin\phi + IR_a\cos\phi}{IX_Q\cos\phi - IR_a\sin\phi}\right) \tag{5.4}$$

where

$$X_a = \omega(L_a + M_{ab}) \tag{5.5}$$

$$X_{sa} = \frac{3}{2}\,\omega L_{sa} \tag{5.6}$$

$$X_Q = X_a - X_{sa} \tag{5.7}$$

(2) $I_f - I_s$ from

$$I_f - I_s = \frac{IX_a\cos\phi + IX_{sa}\cos(2\theta_o + \phi) - IR_a\sin\phi}{X_{af}\cos\theta_o} \tag{5.8}$$

where $$X_{af} = \omega M_{af} \tag{5.9}$$

(3) λ_f from

$$I_f = L_f(I_f - I_s) - \frac{3}{2} M_{af} I\cos(\theta_o + \phi) \tag{5.10}$$

(4) I_s from

$$I_s = C(\lambda_f - \lambda_s)^2 \tag{5.11}$$

(5) I_f from

$$I_f = I_s + (I_f - I_s) \tag{5.12}$$

(6) E_f from

$$E_f = L_f R_f \tag{5.13}$$

(7) e_2 from

$$e_2 = \frac{3}{\pi} k_2 V_{\ell\ell} \tag{5.14}$$

(8) E_{ref} from

$$E_{ref} = \frac{3}{\pi} k_2 V_{\ell\ell} + \frac{1}{k_3}(R_m + R_f)I_s \tag{5.15}$$

(9) $e_4' = e_2'$. (5.16)

When steps (1) through (5) are used, the values of the dependent variables

i_f, i_d, i_q, and θ of the motor of an MG set can be obtained. The value of the field excitation of the motor is provided by Equation (5.13). Using the equation

$$e_{ex} = kV_{\ell\ell} \tag{5.17}$$

the value of k can be calculated. The remaining dependent variable of the motor, ω_m, is obtained by dividing the frequency of the main bus by the number of pole-pairs of the motor.

For induction motors the remaining variables i_α, i_β, θ_o, and ω_m are calculated as follows:

(1) θ_o (by letting $\psi = 0$) from

$$\psi + \theta_o = \tan^{-1}\left(\frac{V + IX_a\sin\phi + IR_a\cos\phi}{IX_a\cos\phi - IR_a\sin\phi}\right) \tag{5.18}$$

(2) i_α equal I' (since $\psi = 0$), where

$$I' = \frac{IX_a\cos\phi - IR_a\sin\phi}{X_{a\alpha}\cos\theta_o} \tag{5.19}$$

(3) $i_\beta = 0$ (since $\psi = 0$) (5.20)

(4) s from

$$s = \frac{R'_a}{X_\alpha}\cot(\theta_o + \phi) \tag{5.21}$$

(5) ω_m from

$$\omega_m = \frac{(1 - s)\omega}{n} \quad . \tag{5.22}$$

The electromagnetic torque of the motor must equal the mechanical

torque of the load of the motor which is given by the equation

$$\tau = \frac{nR_{a'} I'^2}{s\omega} . \quad (5.23)$$

The dependent variables of the distribution transformer are the secondary currents i_A, i_B, and i_C which are given by the equations

$$i_A = -\frac{aI}{\sqrt{3}} \cos(\phi + \frac{5\pi}{6}) \quad (5.24)$$

$$i_B = \frac{aI}{\sqrt{3}} \cos(\phi - \frac{\pi}{2}) \quad (5.25)$$

$$i_C = \frac{aI}{\sqrt{3}} \cos(\phi + \frac{\pi}{6}) . \quad (5.26)$$

The maximum amplitude of the secondary line-to-line voltages can be computed by using a phasor diagram and taking into consideration the leakage-reactance and winding resistance of the transformer.

In addition to the values of the dependent variables of the commercial power system previously described, the values of the maximum amplitude, E_{U2}, and of the phase angle, χ, of the voltage source are obtained from a phasor diagram which considers the various reactance and resistance drops of the interconnection transformer, transmission line, and power source.

As can be seen from this section, getting the initial values of the dependent variables and other required initial conditions is, to say the least, tedious; however, for a given power plant configuration, this only has to be done once. For subsequent simulations the values from a steady-state run can be used.

In arriving at Equations (5.1) through (5.25), the convention used for stator currents and for the polarity of terminal voltages is that shown in Figures 2 through 4. This situation necessitates that the range of ϕ for alternators be from $-\frac{\pi}{2}$ to 0 for leading power factors and from 0 to $\frac{\pi}{2}$ for lagging power factors. The range of ϕ for motors is from $\frac{\pi}{2}$ to π for leading power factors, and from π to $\frac{3\pi}{2}$ for lagging power factors.

5.6 Input Information Required for Main SPEED and TORQUE Programs

In order to run the SUB2 program, it has already been stated that a MAIN program is required. The data required for the MAIN program should be placed just before the data deck for SUB2 as stated in Section 5.3. A data card must be placed in front of the complete input data deck (both MAIN and SUB2 data decks) which has, in format I5, an integer which is equal to the number of simulations in one computer run.

The included main SPEED program requires 2 data cards. The first card uses format 13A6 and contains a verbal description of the simulation. The second card contains in format 2E10.3 the duration of the simulation in seconds and the speed of the shafts of the generating units in rad/sec.

The included main TORQUE program requires two cards plus a card for each generating unit. The first card contains a verbal description of the simulation in format 13A6. The second card contains the number of generating units, the integrating time steps, and the duration of the simulation in seconds in format I5, 2E10.4. The succeeding cards for each generating unit have a format of 3E10.4 which contains the

initial value of the mechanical speed of the shaft of the generating unit in rad/sec, the developed mechanical torque of the shaft in ft-lb, and the total inertia of the shaft in lb-ft^2.

CHAPTER 6

COMPUTER PROGRAM MODIFICATION AND POWER PLANT SIMULATION

6.1 Program Modification

When the original program was developed, each subroutine was verified to operate properly when run by itself, but a complete power plant simulation utilizing the full SUB2 program was never attempted. Originally, the power plant to be simulated consisted of fewer components than that shown in Figure 1 and contained a duplex reactor which was to be used to drive the high voltage power supplies. In the modified program of Appendix C, a few statements referring to the duplex reactor remain, since removing them would have necessitated a larger amount of program reorganization and renumbering. These additional FORTRAN statements require very little additional computer space.

In order to make the computer program compatible with the power plant of Figure 1, the following modifications were made: (1) The dimensions of the common arrays were lengthened; (2) the L array was reorganized and the corresponding FORTRAN statements in the various subroutines were changed to reflect the reorganization of the L array; and (3) a few minor programming errors were corrected. All of the FORTRAN statements which were changed have been noted by shifting the identification sequence numbers to the left 1 space. This should simplify future program changes due to subsequent power plant modifications.

6.2 Development of a Complete Power Plant Simulation

The final,full power plant simulation was the conclusion of

several small simulations. The first step consisted of a simulation consisting of the commercial power source supplying a RL load; the next simulation consisted of commercial power supplying a RL load and an MG set; then commercial power supplying a RL load, an MG set, and an induction motor; and, then commercial power supplying a RL load, an MG set, an induction motor, and a distribution transformer. This methodical approach allows each subroutine to be checked for proper operation before complicating the analysis by adding more components. Using this method, the minor programming errors were found.

The next step was to repeat the above simulations, but to use 4 diesel generators instead of the commercial power source. The reason for using 4 diesel generators instead of 1 is that the 4 diesels will be used in several later simulations.

After verifying that the basic system performed properly, using first a commercial power source and then 4 diesel generators, the rest of the components of Figure 1 were added. A simulation was made with each source of power — commercial power or 4 diesel generators — supplying the full power plant. This step was necessary in order to synchronize the commercial power source with the 4 diesel generators for parallel operation. After completing the two individual simulations, the phase currents of the main bus were plotted for each simulation and the phase angle, χ, of the commercial power source was changed to synchronize the 4 diesel generators with the commercial power source. With both the commercial power source and 4 diesel generators operating in parallel, a steady-state run of .75 second duration was conducted. The initial conditions obtained from this run were then used for all subsequent simulations using this particular power

plant configuration. Each time a simulation was run it took a short period of time for the program to reach steady state since all the derivatives are set to zero prior to the start of the simulation.

6.3 Loss of Commercial Power Simulation

Table 1 contains the input information required in the standard input format form specified in Section 5.3 for the SUB2 and main SPEED programs. The power plant simulated is identical to that of Figure 1 except that it has 4 vice 6 diesel generators, 8 vice 9 MG sets, and 15 vice 16 distribution transformers. The RL load is adjusted so that the power plant is initially operating at 50 percent of its capacity. The diesel generators are operating at 55 percent of their capacity and are supplying 50 percent of the power required by the power plant. The commercial power source supplies the other 50 percent of the required power. The whole power plant is operating at a 0.8 power factor. The integrating step throughout the simulation is .0003 seconds.

At 1 second, a single-phase fault occurs at the primary side of the commercial power interconnection transformer; at 1.1 seconds, the commercial power system is removed from the main bus.

Some of the results of the simulation are plotted in Figures 9 and 10. Figure 9 is the instantaneous three-phase power of a diesel generator versus time, and Figure 10 is the percent error of the line-a to line-b voltage of the main bus versus time. Additional results could be plotted, but these two figures exemplify what can be obtained from the program. Again, it must be mentioned, a more complicated and precise MAIN program is needed to accurately simulate the power plant.

TABLE 1. INPUT DATA REQUIRED FOR TRANSIENT SIMULATION

```
    1
 TRANSIENT RUN FOR THESIS
 4.0          37.69911
 TRANSIENT RUN WITH FAULT ON AND THEN LOSS OF COM PWR: INITIALLY
USING COMMERCIAL POWER SOURCE AND 4 GENERATORS FEEDING AND RL LOAD
AND 2 WEST., ROQUE II, III, + IV MG SETS, 4 IM, 15 DIST TRANS

 FAULT ON COM PWR AT 1.0 SEC, LOSE COM PWR AT 1.1 SEC:

I X   1    1 0.0
I C   1    6 .0003        5883.13     9.1202      9.1202      9.1202      .018144
I C   7   12 .018144      .018144     3600.       3600.       3600.       0.0
I C  13   15 3600.        0.0         0.0
I L   1    5 4.1          8.1         4.1         15.1        1.1
I L   7   10 0.0          1.1         30.1        0.0
I L100 105 1.1            1.1         1.1         1.1         2.1         2.1
I L106 111 2.1            2.1         2.1         2.1         2.1         2.1
I L112 117 3.1            3.1         3.1         3.1         4.1         4.1
I L118 123 4.1            4.1         4.1         4.1         4.1         4.1
I L124 129 4.1            4.1         4.1         4.1         4.1         4.1
I L130 130 4.1
I C 35   40 .00046        .01728      .00035      .003456     .000193     .0173
I C 41   46 2522.         5.9742      3600.       0.0         3600.       1.1
I C 47   48 1.0           3600.
I A 1 1   6 .005806       .002487     .00153      .22884      .00201      .003754
I A 1 7  12 9.286         .07         .0006694    .004667     .0262       2.08
I A 113  17 .00675        .11383      10.         195.014     .0002205
I A 120  25 3600.         0.0         111.4       .4          .0178       .06
I A 126  31 .0036364      40.182      .1          .03248      1.0         52.
I A 132  33 500.          2000.
I B 114  14 116.599
I Y  1    6 319.257       -294.213    -25.044     56.547      .7063       -.0722
I Y  7   11 4.892         419.018     -.2729      101.015     -.01228
I F  9    9 -.0404
I A 2 1   6 .005806       .002487     .00153      .22884      .00201      .003754
I A 2 7  12 9.286         .07         .0006694    .004667     .0262       2.08
I A 213  17 .00675        .11383      10.         195.014     .0002205
I A 220  25 3600.         0.0         111.4       .4          .0178       .06
I A 226  31 .0036364      40.182      .1          .03248      1.0         52.
I A 232  33 500.          2000.
I B 214  14 116.599
I Y 12   17 319.257       -294.213    -25.044     56.547      .7063       -.0722
I Y 18   22 4.892         419.018     -.2729      101.015     -.01228
I F 20   20 -.0404
I A 3 1   6 .005806       .002487     .00153      .22884      .00201      .003754
I A 3 7  12 9.286         .07         .0006694    .004667     .0262       2.08
I A 313  17 .00675        .11383      10.         195.014     .0002205
I A 320  25 3600.         0.0         111.4       .4          .0178       .06
```

TABLE 1. — CONTINUED

I	A	326	31	.0036364	40.182	.1	.03248	1.0	52.
I	A	332	33	500.	2000.				
I	B	314	14	116.599					
I	Y	23	28	319.257	-294.213	-25.044	56.547	.7063	-.0722
I	Y	29	33	4.892	419.018	-.2729	101.015	-.01228	
I	F	31	31	-.0404					
I	A	4 1	6	.005806	.002487	.00153	.22884	.00201	.003754
I	A	4 7	12	9.286	.07	.0006694	.004667	.0262	2.08
I	A	413	17	.00675	.11383	10.	195.014	.0002205	
I	A	420	25	3600.	0.0	111.4	.4	.0178	.06
I	A	426	31	.0036364	40.182	.1	.03248	1.0	52.
I	A	432	33	500.	2000.				
I	B	414	14	116.599					
I	Y	34	39	319.257	-294.213	-25.044	56.547	.7063	-.0722
I	Y	40	44	4.892	419.018	-.2729	101.015	-.01228	
I	F	42	42	-.0404					
I	A	5 1	6	.010575	.004711	.003431	.171649	.005054	.006145
I	A	5 7	12	2.82	.07	.002506	.008575	.0527	1.058
I	A	513	17	.016295	.095277	3.	95.888	.005894	
I	A	520	25	3600.	0.0	.012739	0.0	6.0	200.
I	A	526	26	16377.					
I	A	531	36	.00841	.003785	.0028	.13096	.005554	.005046
I	A	537	42	1.828	.07	.003268	.005847	.0236	.528
I	A	543	46	.022256	.129939	80.432	.0068013		
I	A	549	54	106.447	.4	.0178	.0603	.003636	31.159
I	A	555	60	.1	.094425	1.	13.2	234.5	2000.
I	A	561	61	0.0					
I	A	568	73	5883.13	0.	52.85	.143	3600.	3600.
I	A	574	79	0.0	3600.	3600.	0.0	3600.	0.0
I	A	580	80	0.0					
I	B	542	42	45.2526					
I	Y	45	50	-31.4429	12.675	18.767	70.656	-.53212	.05129
I	Y	51	56	4.669	125.664	29.083	-44.267	15.185	87.538
I	Y	57	62	-.06343	-.0011	4.667	201.05	-.01149	99.989
I	Y	63	63	.46029					
I	F	61	61	.006405					
I	A	6 1	6	.010575	.004711	.003431	.171649	.005054	.006145
I	A	6 7	12	2.82	.07	.002506	.008575	.0527	1.058
I	A	613	17	.016295	.095277	3.	95.888	.005894	
I	A	620	25	3600.	0.0	.012739	0.0	6.	200.
I	A	626	26	16377.					
I	A	631	36	.00841	.003785	.0028	.13096	.005554	.005046
I	A	637	42	1.828	.07	.003268	.005847	.0236	.528
I	A	643	46	.022256	.129939	80.432	.0068013		
I	A	649	54	106.447	.4	.0178	.0603	.003636	31.159
I	A	655	60	.1	.094425	1.	13.2	234.5	2000.
I	A	661	61	0.0					
I	A	668	73	5883.13	0.	52.85	.143	3600.	3600.

TABLE 1. — CONTINUED

I	A	674	79	0.0	3600.	3600.	0.0	3600.	0.0
I	A	680	80	0.0					
I	B	642	42	45.2526					
I	Y	64	69	-31.4429	12.675	18.767	70.656	-.53212	.05129
I	Y	70	75	4.669	125.664	29.083	-44.267	15.185	87.538
I	Y	76	81	-.06343	-.0011	4.667	201.05	-.01149	99.989
I	Y	82	82	.46029					
I	F	80	80	.006405					
I	A	7 1	6	.05839	.02607	.017476	.044563	.107495	.035506
I	A	7 7	12	.03509	.07	.19594	.048349	.37184	.11288
I	A	713	17	1.19387	.537214	3.	3.24617	13.8611	
I	A	720	25	3600.	0.0	.010125	0.0	6.	200.
I	A	726	26	5610.					
I	A	731	36	.0000608	.0000274	.0000172	.0231	.0002209	.0000398
I	A	737	42	7.9134	.07	.0008779	.0000486	.0006	2.55
I	A	743	46	.0012204	.000187	91.004	.0004489		
I	A	749	54	41.0667	.4	.1246	.0804	.006465	20.947
I	A	755	60	.13333	.04788	1.3333	63.75	500.	1000.
I	A	761	61	.0000663					
I	A	768	73	294.1	0.0	.1822	.000362	3600.	3600.
I	A	774	79	0.	3600.	3600.	0.0	3600.	0.0
I	A	780	80	0.					
I	B	742	42	61.189					
I	Y	83	88	-29.712	-4.851	34.563	533.05	.001388	.03072
I	Y	89	94	4.538	125.665	394.319	-741.377	347.058	23.726
I	Y	95	100	-7.3879	-.1493	4.421	131.794	-.01677	34.814
I	Y	101	101	-.24796					
I	F	99	99	-.02					
I	A	8 1	6	.05839	.02607	.017476	.044563	.107495	.035506
I	A	8 7	12	.03509	.07	.19594	.048349	.37184	.11288
I	A	813	17	1.19387	.537214	3.	3.24617	13.8611	
I	A	820	25	3600.	0.0	.010125	0.0	6.	200.
I	A	826	26	5610.					
I	A	831	36	.0000608	.0000274	.0000172	.0231	.0002209	.0000398
I	A	837	42	7.9134	.07	.0008779	.0000486	.0006	2.55
I	A	843	46	.0012204	.000187	91.004	.0004489		
I	A	849	54	41.0667	.4	.1246	.0804	.006465	20.947
I	A	855	60	.13333	.04788	1.3333	63.75	500.	1000.
I	A	861	61	.0000663					
I	A	868	73	294.1	0.0	.1822	.000362	3600.	3600.
I	A	874	79	0.	3600.	3600.	0.0	3600.	0.0
I	A	880	80	0.					
I	B	842	42	61.189					
I	Y	102	107	-29.712	-4.851	34.563	533.05	.001388	.03072
I	Y	108	113	4.538	125.665	394.319	-741.377	347.058	23.726
I	Y	114	119	-7.3879	-.1493	4.421	131.794	-.01677	34.814
I	Y	120	120	-.24796					
I	F	118	118	-.02					

TABLE 1. — CONTINUED

I	A 9 1	6	.100766	.045033	.029293	.076394	.105447	.062200
I	A 9 7	12	.060161	.07	.115848	.084047	.80372	.25753
I	A 913	17	.729258	.933853	3.	3.2487	8.07325	
I	A 920	25	3600.	0.0	.0134776	0.0	6.	200.
I	A 926	26	2400.					
I	A 931	36	.000103	.0000456	.0000309	.0231	.0003781	.0000657
I	A 937	42	4.65	.07	.001456	.0000851	.0015	2.34
I	A 943	46	.00254	.000356	53.478	.0018986		
I	A 949	54	44.648	.4	.1246	.0603	.003636	17.8857
I	A 955	60	.1	.04583	1.	58.5	150.	1000.
I	A 961	61	.0000663					
I	A 968	73	294.1	0.0	.2884	.000574	3600.	3600.
I	A 974	79	0.0	3600.	3600.	0.0	3600.	0.0
I	A 980	80	0.					
I	B 942	42	58.363					
I	Y121	126	-18.888	-2.094	20.982	311.023	.01323	-.0441
I	Y127	132	4.5201	125.662	240.833	-469.444	228.61	24.873
I	Y133	138	-1.375	-.2776	4.4016	175.149	-.00737	34.882
I	Y139	139	.2296					
I	F137	137	-.01827					
I	A10 1	6	.100766	.045033	.029293	.076394	.105447	.062200
I	A10 7	12	.060161	.07	.115848	.084047	.80372	.25753
I	A1013	17	.729258	.933853	3.	3.2487	8.07325	
I	A1020	25	3600.	0.0	.0134776	0.0	6.	200.
I	A1026	26	2400.					
I	A1031	36	.000103	.0000456	.0000309	.0231	.0003781	.0000657
I	A1037	42	4.65	.07	.001456	.0000851	.0015	2.34
I	A1043	46	.00254	.000356	53.478	.0018986		
I	A1049	54	44.648	.4	.1246	.0603	.003636	17.8857
I	A1055	60	.1	.04583	1.	58.5	150.	1000.
I	A1061	61	.0000663					
I	A1068	73	294.1	0.0	.2884	.000574	3600.	3600.
I	A1074	79	0.0	3600.	3600.	0.0	3600.	0.0
I	A1080	80	0.					
I	B1042	42	58.363					
I	Y140	145	-18.888	-2.094	20.982	311.023	.01323	-.0441
I	Y146	151	4.5201	125.662	240.833	-469.444	228.61	24.873
I	Y152	157	-1.375	-.2776	4.4016	175.149	-.00737	34.882
I	Y158	158	.2296					
I	F156	156	-.01827					
I	A11 1	6	.028789	.012897	.007627	.018815	.120674	.018566
I	A11 7	12	.013033	.07	.567385	.024553	.15287	.04676
I	A1113	17	4.05774	.272814	3.	2.8541	41.9146	
I	A1120	25	3600.	0.0	.009857	0.0	6.0	200.
I	A1126	26	12900.					
I	A1131	36	.0000308	.0000136	.0000086	.0231	.0001109	.0000201
I	A1137	42	15.5174	.07	.0005065	.0000246	.00021	1.54
I	A1143	46	.001333	.000126	179.45	.0001705		

TABLE 1. — CONTINUED

I	A1149 54	36.2295	.4	.1246	.0603	.003636	90.6858
I	A1155 60	.1	.013736	1.	38.5	500.8	1000.
I	A1161 61	.0000398					
I	A1168 73	294.1	0.	.0824	.0001639	3600.	3600.
I	A1174 79	0.	3600.	3600.	0.0	3600.	0.0
I	A1180 80	0.					
I	B1142 42	38.416					
I	Y159 164	-66.25	-7.189	73.44	1252.76	.00411	-.01396
I	Y165 170	4.5145	125.664	821.904	-1648.94	827.04	24.968
I	Y171 176	-.3497	-.8155	4.392	112.644	-.00555	35.
I	Y177 177	.1377					
I	F175 175	-.01148					
I	A12 1 6	.028789	.012897	.007627	.018815	.120674	.018566
I	A12 7 12	.013033	.07	.567385	.024553	.15287	.04676
I	A1213 17	4.05774	.272814	3.	2.8541	41.9146	
I	A1220 25	3600.	0.0	.009857	0.0	6.0	200.
I	A1226 26	12900.					
I	A1231 36	.0000308	.0000136	.0000086	.0231	.0001109	.0000201
I	A1237 42	15.5174	.07	.0005065	.0000246	.00021	1.54
I	A1243 46	.001333	.000126	178.45	.0001705		
I	A1249 54	36.2295	.4	.1246	.0603	.003636	90.6858
I	A1255 60	.1	.013736	1.	38.5	500.8	1000.
I	A1261 61	.0000398					
I	A1268 73	294.1	0.	.0824	.0001639	3600.	3600.
I	A1274 79	0.	3600.	3600.	0.0	3600.	0.0
I	A1280 80	0.					
I	B1242 42	38.416					
I	Y178 183	-66.25	-7.189	73.44	1252.76	.00411	-.01396
I	Y184 189	4.5145	125.664	821.904	-1648.94	827.04	24.968
I	Y190 195	-.3497	-.8155	4.392	112.644	-.00555	35.
I	Y196 196	.1377					
I	F194 194	-.01148					
I	A13 1 6	.222	.1048	.3289	.2599	1.5	.25
I	A13 7 12	1.0	3600.	2500.	3.0	0.0	0.0
I	A1313 16	373.125	1055.	376.9911	1068.0		
I	Y197 202	-111.24	104.41	6.83	102.78	-101.26	3.6564
I	Y203 203	373.344					
I	A14 1 6	.222	.1048	.3289	.2599	1.5	.25
I	A14 7 12	1.0	3600.	2500.	3.0	0.0	0.0
I	A1413 16	373.125	1055.	376.9911	1068.0		
I	Y204 209	-111.24	104.41	6.83	102.78	-101.26	3.6564
I	Y210 210	373.344					
I	A15 1 6	.222	.1048	.3289	.2599	1.5	.25
I	A15 7 12	1.0	3600.	2500.	3.0	0.0	0.0
I	A1513 16	373.125	1055.	376.9911	1068.0		
I	Y211 216	-111.24	104.41	6.83	102.78	-101.26	3.6564
I	Y217 217	373.344					
I	A16 1 6	.222	.1048	.3289	.2599	1.5	.25

TABLE 1. — CONTINUED

I A16 7 12 1.0	3600.	2500.	3.0	0.0	0.0
I A1613 16 373.125	1055.	376.9911	1068.0		
I Y218 223 -111.24	104.41	6.83	102.78	-101.26	3.6564
I Y224 224 373.344					
I A17 1 6 0.0	.000028	14.575	.1755	.000349	3600.0
I A17 7 12 0.0	3600.	3600.	0.0	3600.0	678.82
I Y225 227 1780.7	-1148.36	-632.33			
I A18 1 6 0.0	.000028	14.575	.1755	.000349	3600.0
I A18 7 12 0.0	3600.	3600.	0.0	3600.0	678.82
I Y228 230 1780.7	-1148.36	-632.33			
I A19 1 6 0.0	.000028	14.453	.1365	.0002716	3600.0
I A19 7 12 0.0	3600.	3600.	0.0	3600.0	678.82
I Y231 233 2284.78	-1494.94	-789.85			
I A20 1 6 0.0	.000028	14.453	.1365	.0002716	3600.0
I A20 7 12 0.0	3600.	3600.	0.0	3600.0	678.82
I Y234 236 2284.78	-1494.94	-789.85			
I A21 1 6 0.0	.00002	14.742	.2048	.000407	3600.0
I A21 7 12 0.0	3600.	3600.	0.0	3600.0	678.82
I Y237 239 1529.83	-966.80	-563.03			
I A22 1 6 0.0	.00002	14.742	.2048	.000407	3600.0
I A22 7 12 0.0	3600.	3600.	0.0	3600.0	678.82
I Y240 242 1529.83	-966.80	-563.03			
I A23 1 6 0.0	.00003	14.699	.2633	.000523	3600.0
I A23 7 12 0.0	3600.	3600.	0.0	3600.0	678.82
I Y243 245 1189.42	-755.42	-433.99			
I A24 1 6 0.0	.00003	14.699	.2633	.000523	3600.0
I A24 7 12 0.0	3600.	3600.	0.0	3600.0	678.82
I Y246 248 1189.42	-755.42	-433.99			
I A25 1 6 0.0	.00002	14.742	.2048	.000407	3600.0
I A25 7 12 0.0	3600.	3600.	0.0	3600.0	678.82
I Y249 251 1529.83	-966.80	-563.03			
I A26 1 6 0.0	.00018	14.729	1.755	.00349	3600.0
I A26 7 12 0.0	3600.	3600.	0.0	3600.0	678.82
I Y252 254 178.44	-113.	-65.443			
I A27 1 6 0.0	.00018	14.729	1.755	.00349	3600.0
I A27 7 12 0.0	3600.	3600.	0.0	3600.0	678.82
I Y255 257 178.44	-113.	-65.443			
I A28 1 6 0.0	.000007	34.189	.09874	.0001964	3600.0
I A28 7 12 0.0	3600.	3600.	0.0	3600.0	294.156
I Y258 260 1375.68	-862.25	-513.42			
I A29 1 6 0.0	.000007	34.189	.09874	.0001964	3600.0
I A29 7 12 0.0	3600.	3600.	0.0	3600.0	294.156
I Y261 263 1375.68	-862.25	-513.42			
I A30 1 6 0.0	.000011	34.214	.16457	.0003274	3600.0
I A30 7 12 0.0	3600.	3600.	0.0	3600.0	294.156
I Y264 266 825.45	-516.74	-308.70			
I A31 1 6 0.0	.000011	34.214	.16457	.0003274	3600.0
I A31 7 12 0.0	3600.	3600.	0.0	3600.0	294.156
I Y267 269 825.45	-516.74	-308.70			
I Y270 272 1313.01	-1462.25	149.24			

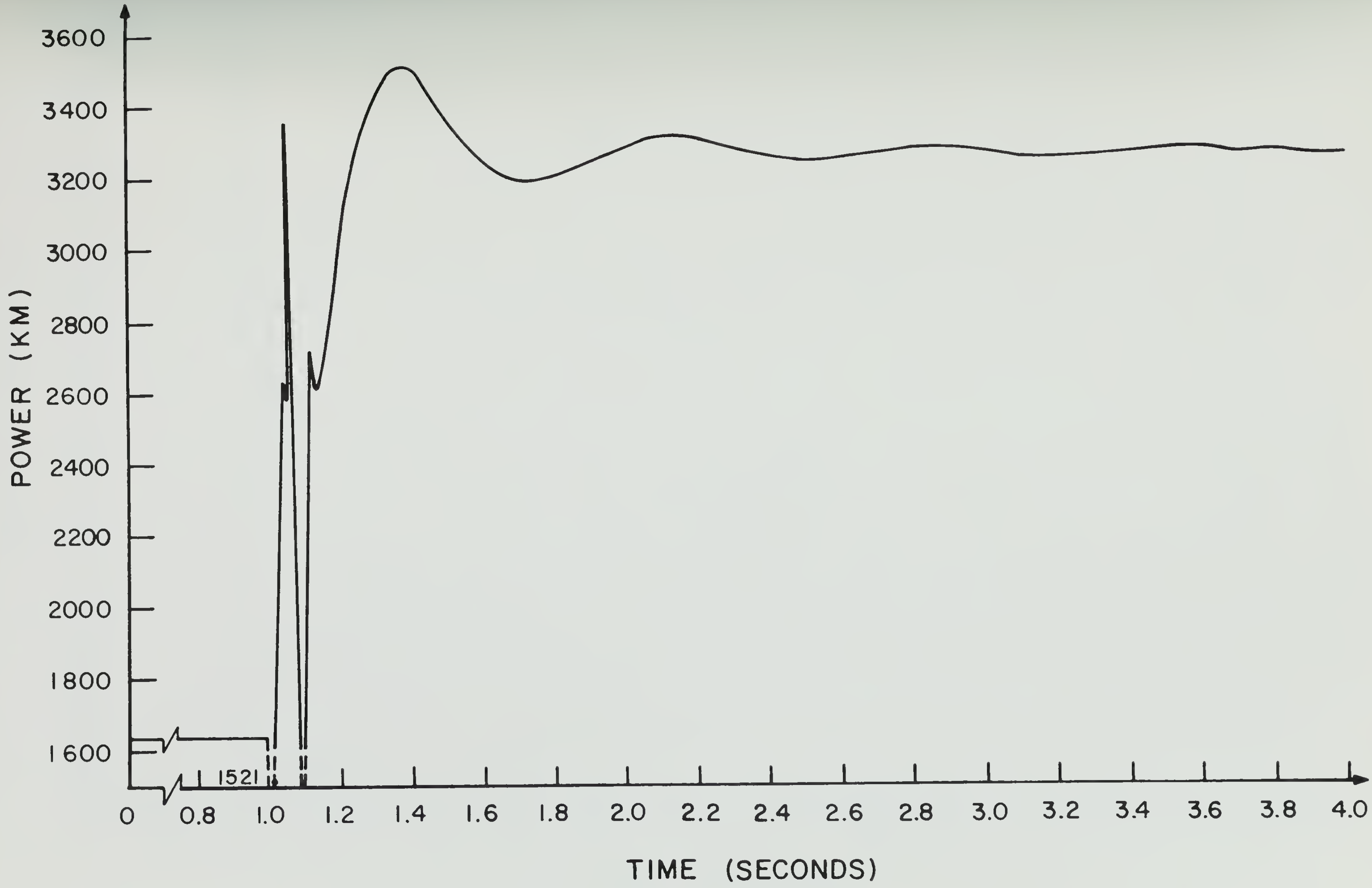

Figure 9. Plot of Instantaneous Three-Phase Power of a Diesel Generator Versus Time

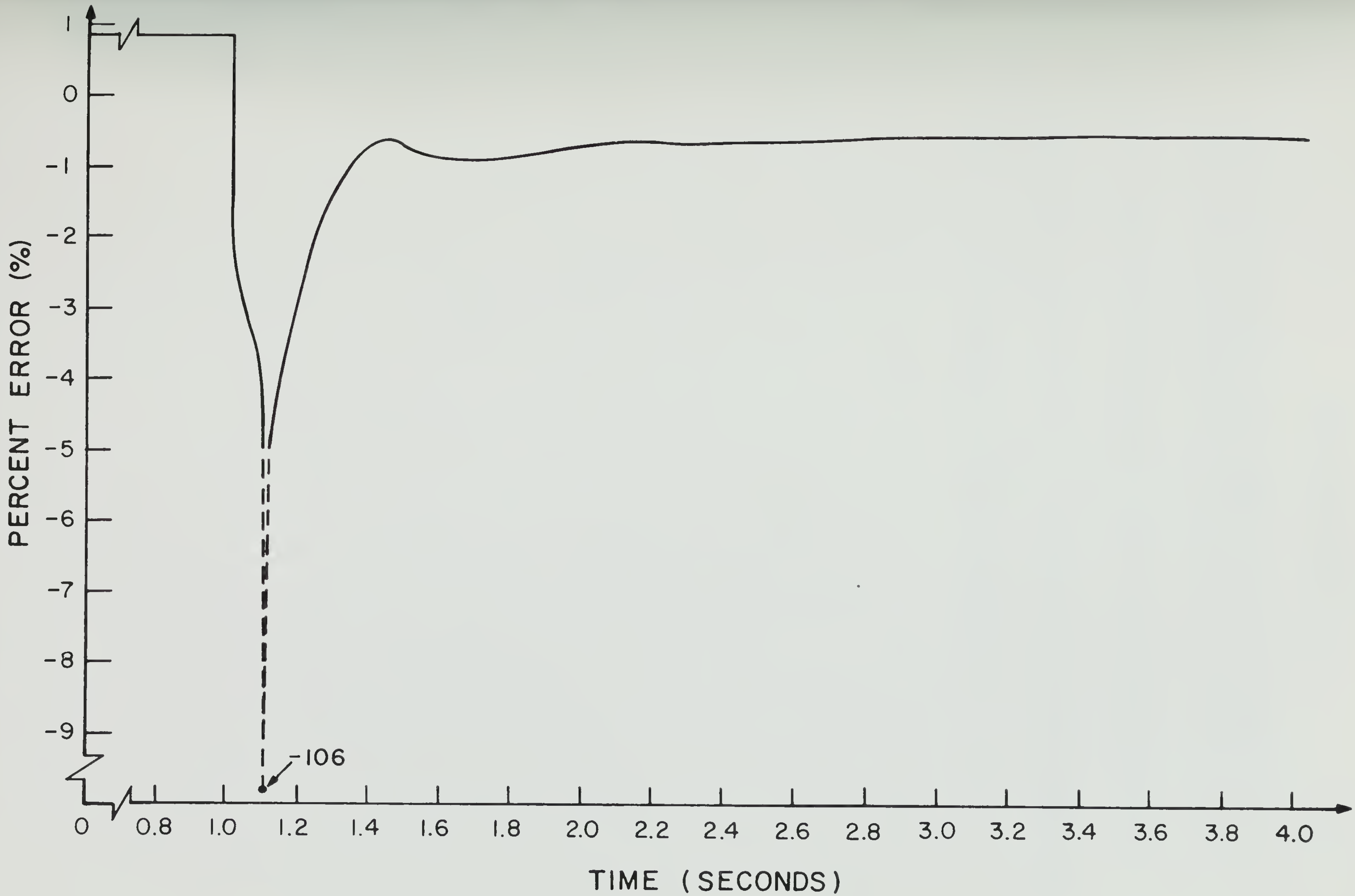

Figure 10. Plot of Percent Error of the Line-a to Line-b Voltage of the Main Bus Versus Time

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APPENDIX A

DEFINITIONS OF ALGEBRAIC SYMBOLS

(pages 49 to 56)

Symbol	Description	Units
a	primary to secondary turns-ratio of transformer	
C	constant in formula for equivalent field saturation current	amp/volt^2-sec
e	instantaneous voltage rise	volt
e_1	output voltage of three-phase, full-wave rectifier in terminal-voltage feedback loop of regulator	volt
e_2	output voltage of quadratic filter in terminal-voltage feedback loop of regulator	volt
e'_2	derivative of e^2 with respect to time	volt/sec
e_3	output voltage of regulator amplifier	volt
E_3	limit of output voltage of regulator amplifier	volt
e_4	output voltage of feedback network in regulator	volt
e'_4	integral of e_4 from time zero to time t	volt-sec
$e_{A'}, e_{B'}, e_{C'}$	instantaneous voltages of phases A', B' and C' of power source in commercial power system	volt
e_{ex}	excitation voltage for synchronous motor	volt
e_f	instantaneous voltage rise of field winding	volt
E_f	value of e_f in balanced steady state	volt
e_{fo}	value of e_f at time zero	volt
E_{ref}	reference voltage of regulator	volt
E_s	limit of field voltage of synchronous alternator due to saturation of exciter transformers	volt
E_U	maximum amplitude of $e_{A'}$, $e_{B'}$ and $e_{C'}$	volt
E_{U2}	maximum amplitude of $e_{A'2}$, $e_{B'2}$ and $e_{C'2}$	volt
i	instantaneous current	amp

Symbol	Description	Units
I	maximum amplitude of phase currents in balanced steady state	amp
I'	maximum amplitude of currents of $\alpha\beta$ rotor windings of induction motor in balanced steady state	amp
i_a, i_b, i_c	instantaneous currents of phases a, b and c	amp
i_A, i_B, i_C	instantaneous currents of phases A, B and C	amp
i_{ab}, i_{bc}, i_{ca}	instantaneous currents of windings ab, bc and ca in Δ-connected side of transformer	amp
i_{AB}, i_{BC}, i_{CA}	instantaneous currents of windings AB, BC and CA in Δ-connected side of transformer	amp
i_d	current of direct amortisseur winding	amp
i_f	instantaneous current of field winding	amp
I_f	value of i_f in balanced steady state	amp
i_{ff}	field-forcing current of exciter of synchronous alternator	amp
$i_{\ell a}, i_{\ell b}, i_{\ell c}$	instantaneous currents of phases a, b and c of RL load of main bus or of load of bus of MG set(s)	amp
i_{LA}, i_{LB}, i_{LC}	instantaneous currents of phases A, B and C of load of distribution transformer	amp
I_m	moment of inertia	
i_q	current of quadrature amortisseur winding	amp
I_s	value of equivalent field saturation current in balanced steady state	amp
i_α, i_β, i_o	instantaneous currents of $\alpha\beta o$ rotor windings of induction motor	amp
I_α	phasor of current of α rotor winding of induction motor	amp
k	gain constant in excitation voltage source of synchronous motor	
k_1	gain constant in reactive-load share control of regulator	volt/amp

Symbol	Description	Units
k_2	gain constant of quadratic filter in terminal-voltage feedback loop of regulator	
k_3	gain constant of regulator amplifier	
L	inductance	henry
L_o	self-inductance of o rotor winding of induction motor	henry
L_0	zero-phase-sequence inductance	henry
L_a	self-inductance of stator windings excluding saliency effects	henry
$L_{a'}$	self-inductance of rotor windings of induction motor	henry
L_d	self-inductance of direct amortisseur winding	henry
L_D	synchronous inductance in direct axis	henry
L'_D	transient inductance in direct axis	henry
L''_D	subtransient inductance in direct axis	henry
$L_{d\ell}$	leakage inductance of direct amortisseur winding	henry
$L_{D\ell}$	leakage inductance of direct-axis stator winding	henry
L_{eq2}	equivalent leakage-inductance of transformer referred to Y-connected secondary	henry
L_f	self-inductance of field winding	henry
$L_{f\ell}$	leakage inductance of field winding	henry
L_ℓ	nominal inductance, per phase, of load of bus of MF set(s)	henry
L_L	nominal inductance, per phase, of load of distribution transformer	henry
$L_{\ell a}, L_{\ell b}, L_{\ell c}$	nominal inductances of phases a, b and c of RL load of main bus	henry
$L'_{\ell a}, L'_{\ell b}, L'_{\ell c}$	instantaneous inductances of phases a, b and c of RL load of main bus or of load of bus of MG set(s)	henry

Symbol	Description	Units
L_{LA}, L_{LB}, L_{LC}	instantaneous inductances of phases A, B and C of load of distribution transformer	henry
L_N	inductance of grounding reactor	henry
L_q	self-inductance of quadrature amortisseur winding	henry
L_Q	synchronous inductance in quadrature axis	henry
L''_Q	subtransient inductance in quadrature axis	henry
$L_{q\ell}$	leakage inductance of quadrature amortisseur winding	henry
$L_{Q\ell}$	leakage inductance of quadrature-axis stator winding	henry
L_{sa}	maximum contribution from saliency to self-inductance of stator windings and to mutual inductance between stator windings	henry
L_T	per-line inductance of overhead transmission line in commercial power system	henry
L_{T2}	equal to L_T divided by a^2	henry
L_U	inductance of per-phase impedance of power source in commercial power system	henry
L_{U2}	equal to L_U divided by a^2	henry
L_α	self-inductance of $\alpha\beta$ rotor windings of induction motor	henry
M	mutual inductance	henry
$M_{aa'}$	maximum mutual inductance between stator and rotor windings of induction motor	henry
M_{ab}	mutual inductance between stator windings excluding saliency effects	henry
$M_{a'b'}$	mutual inductance between rotor windings of induction motor	henry
M_{ad}	maximum mutual inductance between stator and direct amortisseur windings	henry
M_{af}	maximum mutual inductance between stator and field windings	henry

Symbol	Description	Units
M_{aq}	maximum mutual inductance between stator and quadrature amortisseur windings	henry
$M_{a\alpha}$	maximum mutual inductance between stator and $\alpha\beta$ rotor windings of induction motor	henry
M_{fd}	mutual inductance between field and direct amortisseur windings	henry
n	number of pole-pairs	
n_1	number of turns in primary winding of transformer	
N_1	equal to the ratio of M_{af} to M_{fd}	
n_2	number of turns in secondary winding of transformer	
N_2	equal to the ratio of M_{af} to M_{fd}	
R	resistance	ohm
R_a	resistance of stator windings	ohm
$R_{a'}$	resistance of rotor windings of induction motor	ohm
R_d	resistance of direct amortisseur winding	ohm
R_{eq2}	equivalent winding-resistance of transformer referred to Y-connected secondary	ohm
R_f	resistance of field winding	ohm
R_ℓ	nominal resistance, per phase, of load of bus of MG set(s)	ohm
R_L	nominal resistance, per phase, of load of distribution transformer	ohm
R_L'	secondary load-resistance in transformer equivalent of induction motor	ohm
R_{LA}, R_{LB}, R_{LC}	instantaneous resistances of phases A, B and C of load of distribution transformer	ohm
R_m	magnetizing impedance of exciter transformers of synchronous alternator	ohm

Symbol	Description	Units
R_q	resistance of quadrature amortisseur winding	ohm
R_T	per-line resistance of overhead transmission line in commercial power system	ohm
R_{T2}	equal to R_T divided by a^2	ohm
R_U	resistance of per-phase impedance of power source in commercial power system	ohm
R_{U2}	equal to R_U divided by a^2	ohm
s	fractional slip of rotor of induction motor	sec^{-1}
t	time	sec
t_2	time constant of quadratic filter in terminal-voltage feedback loop of regulator	sec
t_2'	time constant of quadratic filter in terminal-voltage feedback loop of regulator	sec^2
t_3	time delay of regulator amplifier	sec
t_4	time constant of feedback network in regulator	sec
t_4'	time delay of feedback network in regulator	sec
T''_{do}	open-circuit time constant of direct amortisseur winding	sec
T''_{ds}	short-circuit time constant of direct amortisseur winding	sec
t_{ef}	effective field time constant of loaded machine	sec
T'_{fo}	open-circuit time constant of field winding	sec
T'_{fs}	short-circuit time constant of field winding	sec
T''_{qo}	open-circuit time constant of quadrature amortisseur winding	sec
T''_{qs}	short-circuit time constant of quadrature amortisseur winding	sec
T_r	recovery time for step load change	sec

Symbol	Description	Units
V	maximum amplitude of phase terminal voltage drops in balanced steady state	volt
v_a, v_b, v_c	instantaneous terminal voltage drops to ground of phases a, b and c	volt
v_A, v_B, v_C	instantaneous voltage drops to ground of phases A, B and C	volt
v_{ab},v_{bc},v_{ca}	instantaneous terminal voltages of line-a-to-line-b, line-b-to-line-c and line-c-to-line-a	volt
v_{AB},v_{BC},v_{CA}	instantaneous voltages of line-A-to-line-B, line-B-to-line-C and line-C-to-line-A	volt
$V_{\ell\ell}$	maximum amplitude of line-to-line terminal voltage	volt
v_N	instantaneous voltage drop of grounding reactor	volt
X	reactance	ohm
X_a	synchronous reactance in direct and quadrature axes excluding saliency effects	ohm
$X_{aa'}$	mutual reactance, based on stator frequency, between stator and rotor windings in transformer equivalent of induction motor	ohm
$X_{a\ell}$	leakage reactance of stator windings in transformer equivalent of induction motor	ohm
$X_{a'\ell}$	leakage reactance, based on stator frequency, of rotor windings in transformer equivalent of induction motor	ohm
$X_{a\alpha}$	mutual reactance, based on stator frequency, between stator and $\alpha\beta$ rotor windings in transformer equivalent of induction motor	ohm
X_D	synchronous reactance in direct axis	ohm
X_Q	synchronous reactance in quadrature axis	ohm
X_α	self-reactance, based on stator frequency, of $\alpha\beta$ rotor windings in transformer equivalent of induction motor	ohm

Symbol	Description	Units
Δf	electrical speed deviation for application and removal of field excitation in synchronous motor	cps
θ	electrical angle of axis of field winding, or of α rotor winding in induction motor, with respect to axis of phase-a stator winding, measured in direction of rotor's rotation	rad
θ_o	value of θ at time zero	rad
θ_m	mechanical angle of rotation of rotor	rad
λ	instantaneous flux linkages	volt-sec
λ_D, λ_Q, λ_0	instantaneous flux linkages of DQO stator windings	volt-sec
λ_f	instantaneous flux linkages of field winding	volt-sec
λ_q	instantaneous flux linkages of quadrature amortisseur winding	volt-sec
λ_s	value of λ_f at which field saturation begins	volt-sec
λ_α, λ_β, λ_o	instantaneous flux linkages of $\alpha\beta o$ rotor windings of induction motor	volt-sec
τ	electromagnetic torque	
ϕ	power factor angle	rad
χ	phase angle of $e_{A'}$ at time zero	rad
ψ	phase angle used in currents of $\alpha\beta$ rotor windings of induction motor	rad
ω	electrical speed of rotor, or electrical frequency	rad/sec
ω_m	mechanical speed of rotor	rad/sec

APPENDIX B

MAJOR FORTRAN ARRAYS USED IN SUB2 PROGRAM

(pages 58 to 92)

A Array (in COMMON, Dimensions: 80 x 35)

Generators of Generating Units

Fortran	Description	Units	Algebraic
A(1,I)	self-inductance of stator windings excluding saliency effects	henry	L_a
A(2,I)	mutual inductance between stator windings excluding saliency effects	henry	M_{ab}
A(3,I)	maximum contribution from saliency to self-inductance of stator windings and to mutual inductance between stator windings	henry	L_{sa}
A(4,I)	maximum mutual inductance between stator and field windings	henry	M_{af}
A(5,I)	maximum mutual inductance between stator and direct amortisseur windings	henry	M_{ad}
A(6,I)	maximum mutual inductance between stator and quadrature amortisseur windings	henry	M_{aq}
A(7,I)	self-inductance of field winding	henry	L_f
A(8,I)	mutual inductance between field and direct amortisseur windings	henry	M_{fd}
A(9,I)	self-inductance of direct amortisseur winding	henry	L_d
A(10,I)	self-inductance of quadrature amortisseur winding	henry	L_q
A(11,I)	resistance of stator windings	ohm	R_a
A(12,I)	resistance of field winding	ohm	R_f
A(13,I)	resistance of direct amortisseur winding	ohm	R_d
A(14,I)	resistance of quadrature amortisseur winding	ohm	R_q
A(15,I)	number of pole-pairs		n

Fortran	Description	Units	Algebraic
A(16,I)	value of field flux linkages at which field saturation begins	volt-sec	λ_s
A(17,I)	constant in formula for equivalent field saturation current	amp/volt^2-sec^2	C
A(18,I) & A(19,I)	not used		
A(20,I)	time of removing generator from main bus	sec	
A(21,I)	inductance of grounding reactor	henry	L_N
A(22,I)	reference voltage of regulator	volt	E_{ref}
A(23,I)	gain constant in reactive-load share control of regulator	volt/amp	k_1
A(24,I)	gain constant of quadratic filter in terminal-voltage feedback loop of regulator		k_2
A(25,I)	time constant of quadratic filter in terminal-voltage feedback loop of regulator	sec	t_2
A(26,I)	time constant of quadratic filter in terminal-voltage feedback loop of regulator	sec^2	t'_2
A(27,I)	gain constant of regulator amplifier		k_3
A(28,I)	time delay of regulator amplifier	sec	t_3
A(29,I)	time constant of feedback network in regulator	sec	t_4
A(30,I)	time delay of feedback network in regulator	sec	t'_4
A(31,I)	magnetizing impedance of exciter transformers	ohm	R_m
A(32,I)	limit of field voltage due to saturation of exciter transformers	volt	E_s

Fortran	Description	Units	Algebraic
A(33,I)	limit of output voltage of regulator amplifier	volt	E_3
A(34,I) & A(35,I)	not used		
A(36,I)	value of field voltage at time zero	volt	e_{fo}
A(37,I)	output voltage, at time zero, of feedback network in regulator	volt	$\left.\frac{de'_4}{dt}\right\|_o$
A(38,I) to A(80,I)	not used		

Motor-Generator (MG) Sets

Motors

Fortran	Description	Units	Algebraic
A(1,I)	self-inductance of stator windings excluding saliency effects	henry	L_a
A(2,I)	mutual inductance between stator windings excluding saliency effects	henry	M_{ab}
A(3,I)	maximum contribution from saliency to self-inductance of stator windings and to mutual inductance between stator windings	henry	L_{sa}
A(4,I)	maximum mutual inductance between stator and field windings	henry	M_{af}
A(5,I)	maximum mutual inductance between stator and direct amortisseur windings	henry	M_{ad}
A(6,I)	maximum mutual inductance between stator and quadrature amortisseur windings	henry	M_{aq}
A(7,I)	self-inductance of field winding	henry	L_f
A(8,I)	mutual inductance between field and direct amortisseur windings	henry	M_{fd}

Fortran	Description	Units	Algebraic
A(9,I)	self-inductance of direct amortisseur winding	henry	L_d
A(10,I)	self-inductance of quadrature amortisseur winding	henry	L_q
A(11,I)	resistance of stator windings	ohm	R_a
A(12,I)	resistance of field winding	ohm	R_f
A(13,I)	resistance of direct amortisseur winding	ohm	R_d
A(14,I)	resistance of quadrature amortisseur winding	ohm	R_q
A(15,I)	number of pole-pairs		n
A(16,I)	value of field flux linkages at which field saturation begins	volt-sec	λ_s
A(17,I)	constant in formula for equivalent field saturation current	amp/volt^2-sec^2	C
A(18,I) & A(19,I)	not used		
A(20,I)	time of removing MG set from main bus	sec	
A(21,I)	inductance of grounding reactor	henry	L_n
A(22,I)	gain constant in excitation voltage source		k
A(23,I)	indicator of source of excitation voltage ≥ 0, from lines a and b of main bus < 0, from lines b and c of main bus		
A(24,I)	electrical speed deviation for application and removal of field excitation	cps	Δf
A(25,I)	field discharge resistance	ohm	R_{fd}
A(26,I)	total moment of inertia of MG set	lb-ft^2	I_m
A(27,I) to A(30,I)	not used		

Fortran	Description	Units	Algebraic
	Generators		
A(31,I)	self-inductance of stator windings excluding saliency effects	henry	L_a
A(32,I)	mutual inductance between stator windings excluding saliency effects	henry	M_{ab}
A(33,I)	maximum contribution from saliency to self-inductance of stator windings and to mutual inductance between stator windings	henry	L_{sa}
A(34,I)	maximum mutual inductance between stator and field windings	henry	M_{af}
A(35,I)	maximum mutual inductance between stator and direct amortisseur windings	henry	M_{ad}
A(36,I)	maximum mutual inductance between stator and quadrature amortisseur windings	henry	M_{aq}
A(37,I)	self-inductance of field winding	henry	L_f
A(38,I)	mutual inductance between field and direct amortisseur windings	henry	M_{fd}
A(39,I)	self-inductance of direct amortisseur winding	henry	L_d
A(40,I)	self-inductance of quadrature amortisseur winding	henry	L_q
A(41,I)	resistance of stator windings	ohm	R_a
A(42,I)	resistance of field winding	ohm	R_f
A(43,I)	resistance of direct amortisseur winding	ohm	R_d
A(44,I)	resistance of quadrature amortisseur winding	ohm	R_q
A(45,I)	value of field flux linkages at which field saturation begins	volt-sec	λ_s

Fortran	Description	Units	Algebraic
A(46,I)	constant in formula for equivalent field saturation current	amp/volt^2-sec^2	C
A(47,I) & A(48,I)	not used		
A(49,I)	reference voltage of regulator	volt	E_{ref}
A(50,I)	gain constant in reactive-load share control of regulator	volt/amp	k_1
A(51,I)	gain constant of quadratic filter in terminal-voltage feedback loop of regulator		k_2
A(52,I)	time constant of quadratic filter in terminal-voltage feedback loop of regulator	sec	t_2
A(53,I)	time constant of quadratic filter in terminal-voltage feedback loop of regulator	sec^2	t'_2
A(54,I)	gain constant of regulator amplifier		k_3
A(55,I)	time delay of regulator amplifier	sec	t_3
A(56,I)	time constant of feedback network in regulator	sec	t_4
A(57,I)	time delay of feedback network in regulator	sec	t'_4
A(58,I)	magnetizing impedance of exciter transformers	ohm	R_m
A(59,I)	limit of field voltage due to saturation of exciter transformers	volt	E_s
A(60,I)	limit of output voltage of regulator amplifier	volt	E_3
A(61,I)	inductance of grounding reactor	henry	L_N
A(62,I) to A(65,I)	not used		

Fortran	Description	Units	Algebraic
A(66,I)	value of field voltage at time zero	volt	e_{fo}
A(67,I)	output voltage, at time zero, of feedback network in regulator	volt	$\left.\frac{de'_4}{dt}\right\|_o$
	Buses of MG Sets		
A(68,I)	rated maximum line-to-line voltage	volt	
A(69,I)	indicator for parallel operation of two MG sets ≥ 0, MG set is connected to its own bus < 0, MG set is connected to bus of preceding MG set		
A(70,I)	nominal resistance, per phase, of load	ohm	R_ℓ
A(71,I)	nominal inductance, per phase, of load	henry	L_ℓ
A(72,I)	time of disconnecting the generator from bus	sec	
A(73,I)	time of commencement of step change in load	sec	
A(74,I)	fractional step change of load		
A(75,I)	time of commencement of fault on bus	sec	
A(76,I)	time of termination of fault on bus	sec	
A(77,I)	describes type of fault on bus < 1, no fault $= 1$, single-phase (a) fault $= 2$, two-phase (a and b) fault $= 3$, three-phase (a, b and c) fault ≥ 4, line-to-line (a to b) fault		
A(78,I)	time of commencement of sinusoidal variation of load	sec	
A(79,I)	angular frequency of sinusoidal variation of load	rad/sec	
A(80,I)	fractional amplitude of sinusoidal variation of load		

Fortran	Description	Units	Algebraic
Induction Motors			
A(1,I)	self-inductance of stator windings	henry	L_a
A(2,I)	mutual inductance between stator windings	henry	M_{ab}
A(3,I)	self-inductance of $\alpha\beta$ rotor windings	henry	L_α
A(4,I)	maximum mutual inductance between stator and $\alpha\beta$ rotor windings	henry	$M_{a\alpha}$
A(5,I)	resistance of stator windings	ohm	R_a
A(6,I)	resistance of rotor windings	ohm	$R_{a'}$
A(7,I)	number of pole-pairs		n
A(8,I)	time of removing motor from main bus	sec	
A(9,I)	total moment of inertia of motor and its mechanical load	$lb\text{-}ft^2$	I_m
A(10,I)	number of entries in table of mechanical torque vs. mechanical speed		
A(11,I) to A(80,I)	table of mechanical torque vs. mechanical speed A(11,I), A(13,I) and so on are the speeds in rad/sec; A(12,I), A(14,I) and so on are the corresponding torques in ft-lb.		
Distribution Transformers			
A(1,I)	equivalent winding-resistance of transformer referred to Y-connected secondary	ohm	R_{eq2}
A(2,I)	equivalent leakage-inductance of transformer referred to Y-connected secondary	henry	L_{eq2}
A(3,I)	primary to secondary turns-ratio		a
A(4,I)	nominal resistance, per phase, of load	ohm	R_L

Fortran	Description	Units	Algebraic
A(5,I)	nominal inductance, per phase, of load	henry	L_L
A(6,I)	time of commencement of step change in load	sec	
A(7,I)	fractional step change of load		
A(8,I)	time of commencement of fault on secondary		
A(9,I)	time of termination of fault on secondary		
A(10,I)	describes type of fault on secondary < 1, no fault = 1, single-phase (A) fault = 2, two-phase (A and B) fault = 3, three-phase (A, B and C) fault > 4, line-to-line (A to B) fault		
A(11,I)	time of removing transformer from main bus	sec	
A(12,I)	rated maximum line-to-line voltage of secondary	volt	
A(13,I) to A(19,I)	not used		
A(20,I)	used by VMAXTR as initializing switch		
A(21,I) to A(80,I)	not used		

B Array (in COMMON, Dimensions: 99 x 35)

Generators of Generating Units

Fortran	Description	Units	Algebraic
B(1,I)	instantaneous three-phase power or "average three-phase power"	KW	p, P
B(2,I)	"peak reactive power per phase"	KVA	Q
B(3,I)	electromagnetic torque	ft-lb	τ
B(4,I)	percent rotor speed error		
B(5,I)	electrical speed of rotor	rad/sec	ω
B(6,I)	instantaneous flux linkages of field winding	volt-sec	λ_f
B(7,I)	instantaneous value of equivalent field saturation current	amp	i_s
B(8,I)	derivative of i_s with respect to λ_f	amp/volt-sec	
B(9,I)	$\omega M_{af}\sin\Theta$	ohm	
B(10,I)	$\omega M_{af}\sin(\Theta - \frac{2\pi}{3})$	ohm	
B(11,I)	$\omega M_{af}\sin(\Theta + \frac{2\pi}{3})$	ohm	
B(12,I)	output voltage of three-phase, full-wave rectifier in terminal-voltage feedback loop of regulator	volt	e_1
B(13,I)	field forcing current of exciter	amp	i_{ff}
B(14,I)	instantaneous field voltage	volt	e_f
B(15,I) to B(18,I)	not used		
B(19,I)	$\cos\Theta$		
B(20,I)	$\sin\Theta$		
B(21,I)	$\cos(\Theta + \frac{2\pi}{3})$		
B(22,I)	$\sin(\Theta + \frac{2\pi}{3})$		

Fortran	Description	Units	Algebraic
B(23,I)	$\cos(\Theta - \frac{2\pi}{3})$		
B(24,I)	$\sin(\Theta - \frac{2\pi}{3})$		
B(25,I)	$\cos 2\Theta$		
B(26,I)	$\sin 2\Theta$		
B(27,I)	$\cos(2\Theta + \frac{2\pi}{3})$		
B(28,I)	$\sin(2\Theta + \frac{2\pi}{3})$		
B(29,I)	$\cos(2\Theta - \frac{2\pi}{3})$		
B(30,I)	$\sin(2\Theta - \frac{2\pi}{3})$		
B(31,I) to B(99,I)	not used		

Motor-Generator (MG) Sets

Motors

Fortran	Description	Units	Algebraic
B(1,I)	instantaneous three-phase power or "average three-phase power"	KW	p, P
B(2,I)	"peak reactive power per phase"	KVA	Q
B(3,I)	electromagnetic torque	ft-lb	τ_d
B(4,I)	percent rotor speed error		
B(5,I)	electrical speed of rotor	rad/sec	ω
B(6,I)	instantaneous flux linkages of field winding	volt-sec	λ_f
B(7,I)	instantaneous value of equivalent field saturation current	amp	i_s
B(8,I)	derivative of i_s with respect to λ_f	amp/volt-sec	
B(9,I)	$\omega M_{af}\sin\Theta$	ohm	
B(10,I)	$\omega M_{af}\sin(\Theta - \frac{2\pi}{3})$	ohm	
B(11,I)	$\omega M_{af}\sin(\Theta + \frac{2\pi}{3})$	ohm	

Fortran	Description	Units	Algebraic
B(12,I)	instantaneous field voltage	volt	e_f
B(13,I) to B(18,I)	not used		
B(19,I)	$\cos\Theta$		
B(20,I)	$\sin\Theta$		
B(21,I)	$\cos(\Theta + \frac{2\pi}{3})$		
B(22,I)	$\sin(\Theta + \frac{2\pi}{3})$		
B(23,I)	$\cos(\Theta - \frac{2\pi}{3})$		
B(24,I)	$\sin(\Theta - \frac{2\pi}{3})$		
B(25,I)	$\cos2\Theta$		
B(26,I)	$\sin2\Theta$		
B(27,I)	$\cos(2\Theta + \frac{2\pi}{3})$		
B(28,I)	$\sin(2\Theta + \frac{2\pi}{3})$		
B(29,I)	$\cos(2\Theta - \frac{2\pi}{3})$		
B(30,I)	$\sin(2\Theta - \frac{2\pi}{3})$		
	Generators		
B(31,I)	instantaneous three-phase power or "average three-phase power"	KW	p, P
B(32,I)	"peak reactive power per phase"	KVA	Q
B(33,I)	electromagnetic torque	ft-lb	τ_r
B(34,I)	instantaneous flux linkages of field winding	volt-sec	λ_f
B(35,I)	instantaneous value of equivalent field saturation current	amp	i_s
B(36,I)	derivative of i_s with respect to λ_f	amp/volt-sec	
B(37,I)	$\omega M_{af}\sin\Theta$	ohm	

Fortran	Description	Units	Algebraic
B(38,I)	$\omega M_{af}\sin(\Theta - \frac{2\pi}{3})$	ohm	
B(39,I)	$\omega M_{af}\sin(\Theta + \frac{2\pi}{3})$	ohm	
B(40,I)	output voltage of three-phase, full-wave rectifier in terminal-voltage feedback loop of regulator	volt	e_1
B(41,I)	field forcing current of exciter	amp	i_{ff}
B(42,I)	instantaneous field voltage	volt	e_f
B(43,I) to B(48,I)	not used		
B(49,I)	$\cos\Theta$		
B(50,I)	$\sin\Theta$		
B(51,I)	$\cos(\Theta + \frac{2\pi}{3})$		
B(52,I)	$\sin(\Theta + \frac{2\pi}{3})$		
B(53,I)	$\cos(\Theta - \frac{2\pi}{3})$		
B(54,I)	$\sin(\Theta - \frac{2\pi}{3})$		
B(55,I)	$\cos 2\Theta$		
B(56,I)	$\sin 2\Theta$		
B(57,I)	$\cos(2\Theta + \frac{2\pi}{3})$		
B(58,I)	$\sin(2\Theta + \frac{2\pi}{3})$		
B(59,I)	$\cos(2\Theta - \frac{2\pi}{3})$		
B(60,I)	$\sin(2\Theta - \frac{2\pi}{3})$		
	Buses of MG Sets		
B(61,I)	instantaneous three-phase power or "average three-phase power" of load	KW	p, P
B(62,I)	"peak reactive power per phase" of load	KVA	Q

Fortran	Description	Units	Algebraic
B(63,I)	consecutive display of B(65,I) to B(70,I)		
B(64,I)	consecutive display of B(71,I) to B(73,I)		
B(65,I)	percent error of positive peak of B(77,I)		
B(66,I)	percent error of negative peak of B(77,I)		
B(67,I)	percent error of positive peak of B(78,I)		
B(68,I)	percent error of negative peak of B(78,I)		
B(69,I)	percent error of positive peak of B(79,I)		
B(70,I)	percent error of negative peak of B(79,I)		
B(71,I)	percent error of frequency of B(77,I)		
B(72,I)	percent error of frequency of B(78,I)		
B(73,I)	percent error of frequency of B(79,I)		
B(74,I)	instantaneous voltage drop to ground of phase a	volt	v_a
B(75,I)	instantaneous voltage drop to ground of phase b	volt	v_b
B(76,I)	instantaneous voltage drop to ground of phase c	volt	v_c
B(77,I)	instantaneous line-a-to-line-b voltage	volt	v_{ab}
B(78,I)	instantaneous line-b-to-line-c voltage	volt	v_{bc}
B(79,I)	instantaneous line-c-to-line-a voltage	volt	v_{ca}

Fortran	Description	Units	Algebraic
B(80,I)	instantaneous value of resistance of phase a of load	ohm	$R'_{\ell a}$
B(81,I)	instantaneous value of resistance of phase b of load	ohm	$R'_{\ell b}$
B(82,I)	instantaneous value of resistance of phase c of load	ohm	$R'_{\ell c}$
B(83,I)	instantaneous value of inductance of phase a of load	henry	$L'_{\ell a}$
B(84,I)	instantaneous value of inductance of phase b of load	henry	$L'_{\ell b}$
B(85,I)	instantaneous value of inductance of phase c of load	henry	$L'_{\ell c}$
B(86,I)	instantaneous current of phase a of load	amp	$i_{\ell a}$
B(87,I)	instantaneous current of phase b of load	amp	$i_{\ell b}$
B(88,I)	instantaneous current of phase c of load	amp	$i_{\ell c}$
B(89,I)	time derivative of B(86,I)	amp/sec	
B(90,I)	time derivative of B(87,I)	amp/sec	
B(91,I)	time derivative of B(88,I)	amp/sec	
B(92,I)	used as switch by DISCØN in conjunction with backstepping to integrate to zero phase-a-current when generator is being removed from bus		
B(93,I)	same as B(92,I) but for phase-b-current		
B(94,I)	same as B(92,I) but for phase-c-current		
B(95,I)	used as switch set by DISCØN if B(95,I) is greater than zero, phase a of generator has been disconnected from bus		
B(96,I)	same as B(95,I) but for phase b		

Fortran	Description	Units	Algebraic
B(97,I)	same as B(95,I) but for phase c		
B(98,I)	set equal to I when generator is disconnected from bus		
B(99,I)	used by VMAXGB as initializing switch		

Induction Motors

Fortran	Description	Units	Algebraic
B(1,I)	instantaneous three-phase power or "average three-phase power"	KW	p, P
B(2,I)	"peak reactive power per phase"	KVA	Q
B(3,I)	electromagnetic torque	ft-lb	τ_d
B(4,I)	percent rotor slip		
B(5,I)	electrical speed of rotor	rad/sec	ω
B(6,I)	not used		
B(7,I)	set equal to zero		
B(8,I)	not used		
B(9,I) to B(11,I)	set equal to zero		
B(12,I)	mechanical torque	ft-lb	τ_r
B(13,I) to B(18,I)	not used		
B(19,I)	$\cos\Theta$		
B(20,I)	$\sin\Theta$		
B(21,I)	$\cos(\Theta + \frac{2\pi}{3})$		
B(22,I)	$\sin(\Theta + \frac{2\pi}{3})$		
B(23,I)	$\cos(\Theta - \frac{2\pi}{3})$		
B(24,I)	$\sin(\Theta - \frac{2\pi}{3})$		

Fortran	Description	Units	Algebraic
B(25,I) to B(99,I)	not used		
	Distribution Transformers		
B(1,I)	instantaneous current to phase a of main bus	amp	i_a
B(2,I)	instantaneous current to phase b of main bus	amp	i_b
B(3,I)	instantaneous current to phase c of main bus	amp	i_c
B(4,I)	instantaneous phase-A-to-ground voltage drop of secondary	volt	v_A
B(5,I)	instantaneous phase-B-to-ground voltage drop of secondary	volt	v_B
B(6,I)	instantaneous phase-C-to-ground voltage drop of secondary	volt	v_C
B(7,I)	instantaneous line-A-to-line-B voltage drop of secondary	volt	v_{AB}
B(8,I)	instantaneous line-B-to-line-C voltage drop of secondary	volt	v_{BC}
B(9,I)	instantaneous line-C-to-line-A voltage drop of secondary	volt	v_{CA}
B(10,I)	instantaneous three-phase power or "average three-phase power" of load	KW	p, P
B(11,I)	"peak reactive power per phase" of load	KVA	Q
B(12,I)	consecutive display of B(14,I) to B(19,I)		
B(13,I)	consecutive display of B(20,I) to B(22,I)		
B(14,I)	percent error of positive peak of B(7,I)		
B(15,I)	percent error of negative peak of B(7,I)		

Fortran	Description	Units	Algebraic
B(16,I)	percent error of positive peak of B(8,I)		
B(17,I)	percent error of negative peak of B(8,I)		
B(18,I)	percent error of positive peak of B(9,I)		
B(19,I)	percent error of negative peak of B(9,I)		
B(20,I)	percent error of frequency of B(7,I)		
B(21,I)	percent error of frequency of B(8,I)		
B(22,I)	percent error of frequency of B(9,I)		
B(23,I) to B(30,I)	not used		
B(31,I)	instantaneous value of resistance of phase A of load	ohm	R_{LA}
B(32,I)	instantaneous value of resistance of phase B of load	ohm	R_{LB}
B(33,I)	instantaneous value of resistance of phase C of load	ohm	R_{LC}
B(34,I)	instantaneous value of inductance of phase A of load	henry	L_{LA}
B(35,I)	instantaneous value of inductance of phase B of load	henry	L_{LB}
B(36,I)	instantaneous value of inductance of phase C of load	henry	L_{LC}
B(37,I) & B(38,I)	not used		

Fortran	Description	Units	Algebraic
B(39,I) to B(50,I)	coefficients as indicated below		

$$\frac{di_A}{dt} = B(39,I) + B(40,I)\,\frac{di_{\ell a}}{dt} + B(41,I)\,\frac{di_{\ell b}}{dt} + B(42,I)\,\frac{di_{\ell c}}{dt}$$

$$\frac{di_B}{dt} = B(43,I) + B(44,I)\,\frac{di_{\ell a}}{dt} + B(45,I)\,\frac{di_{\ell b}}{dt} + B(46,I)\,\frac{di_{\ell c}}{dt}$$

$$\frac{di_C}{dt} = B(47,I) + B(48,I)\,\frac{di_{\ell a}}{dt} + B(49,I)\,\frac{di_{\ell b}}{dt} + B(50,I)\,\frac{di_{\ell c}}{dt}$$

Fortran	Description	Units	Algebraic
B(51,I) to B(99,I)	not used		

C Array (in COMMON, Dimension: 50)

Fortran	Description	Units	Algebraic
C(1)	specified integrating time step	sec	
C(2)	rated maximum line-to-line voltage of main bus	volt	
C(3)	nominal resistance of phase a of RL load of main bus	ohm	$R_{\ell a}$
C(4)	nominal resistance of phase b of RL load of main bus	ohm	$R_{\ell b}$
C(5)	nominal resistance of phase c of RL load of main bus	ohm	$R_{\ell c}$
C(6)	nominal inductance of phase a of RL load of main bus	henry	$L_{\ell a}$
C(7)	nominal inductance of phase b of RL load of main bus	henry	$L_{\ell b}$
C(8)	nominal inductance of phase c of RL load of main bus	henry	$L_{\ell c}$
C(9)	time of commencement of fault on main bus	sec	
C(10)	time of termination of fault on main bus	sec	
C(11)	time of commencement of step change in RL load of main bus	sec	
C(12)	fractional step change of RL load of main bus		
C(13)	time of commencement of sinusoidal variation of RL load of main bus	sec	
C(14)	angular frequency of sinusoidal variation of RL load of main bus	rad/sec	
C(15)	fractional amplitude of sinusoidal variation of RL load of main bus		
C(16) to C(34)	not used		

Fortran	Description	Units	Algebraic
C(35)	equivalent leakage-inductance of commercial power interconnection transformer referred to Y-connected secondary	henry	L_{eq2}
C(36)	equivalent winding-resistance of commercial power interconnection transformer referred to Y-connected secondary	ohm	R_{eq2}
C(37)	per-line inductance of overhead transmission line in commercial power system, referred to Y-connected secondary of inter-connection transformer	henry	L_{T2}
C(38)	per-line resistance of overhead transmission line in commercial power system, referred to Y-connected secondary of inter-connection transformer	ohm	R_{T2}
C(39)	per-phase inductance of power source in commercial power system, referred to Y-connected secondary of interconnection transformer	henry	L_{U2}
C(40)	per-phase resistance of power source in commercial power system, referred to Y-connected secondary of interconnection transformer	ohm	R_{U2}
C(41)	maximum amplitude of phase voltages of power source in commercial power system, referred to Y-connected secondary of inter-connection transformer	volt	E_{U2}
C(42)	phase angle, at time zero, of phase-A' voltage of power source in commercial power system	rad	χ
C(43)	time of commencement of step change in amplitude of phase voltages of power source in commercial power system	sec	
C(44)	fractional step change in amplitude of phase voltages of power source in commercial power system		

Fortran	Description	Units	Algebraic
C(45)	time of termination of step change in amplitude of phase voltages of power source in commercial power system	sec	
C(46)	time of removing commercial power system from main bus	sec	
C(47)	time of commencement of fault at primary side of commercial power interconnection transformer	sec	
C(48)	time of termination of fault at primary side of commercial power interconnection transformer	sec	
C(49) & C(50)	not used		

D Array (in COMMON, Dimension: 120)

Fortran	Description	Units	Algebraic
D(1)	consecutive display of D(7) to D(12)		
D(2)	consecutive display of D(13) to D(15)		
D(3)	instantaneous three-phase power or "average three-phase power" of load of main bus	KW	p, P
D(4)	"peak reactive power per phase" of load of main bus	KVA	Q
D(5)	instantaneous three-phase power or "average three-phase power" of commercial power system	KW	p, P
D(6)	"peak reactive power per phase" of commercial power system	KVA	Q
D(7)	percent error of positive peak of D(38)		
D(8)	percent error of negative peak of D(38)		
D(9)	percent error of positive peak of D(39)		
D(10)	percent error of negative peak of D(39)		
D(11)	percent error of positive peak of D(40)		
D(12)	percent error of negative peak of D(40)		
D(13)	percent error of frequency of D(38)		
D(14)	percent error of frequency of D(39)		
D(15)	percent error of frequency of D(40)		
D(16)	instantaneous resistance of phase a of RL load of main bus	ohm	$R'_{\ell a}$

Fortran	Description	Units	Algebraic
D(17)	instantaneous resistance of phase b of RL load of main bus	ohm	$R'_{\ell b}$
D(18)	instantaneous resistance of phase c of RL load of main bus	ohm	$R'_{\ell c}$
D(19)	instantaneous inductance of phase a of RL load of main bus	henry	$L'_{\ell a}$
D(20)	instantaneous inductance of phase b of RL load of main bus	henry	$L'_{\ell b}$
D(21)	instantaneous inductance of phase c of RL load of main bus	henry	$L'_{\ell c}$
D(22)	instantaneous current of phase a of RL load of main bus	amp	$i_{\ell a}$
D(23)	instantaneous current of phase b of RL load of main bus	amp	$i_{\ell b}$
D(24)	instantaneous current of phase c of RL load of main bus	amp	$i_{\ell c}$
D(25)	time derivative of D(22)	amp/sec	
D(26)	time derivative of D(23)	amp/sec	
D(27)	time derivative of D(24)	amp/sec	
D(28)	instantaneous phase-a current of total load of main bus	amp	
D(29)	instantaneous phase-b current of total load of main bus	amp	
D(30)	instantaneous phase-c current of total load of main bus	amp	
D(31)	actual integrating time step	sec	
D(32) to D(34)	not used		
D(35)	instantaneous phase-a-to-ground voltage drop of main bus	volt	v_a
D(36)	instantaneous phase-b-to-ground voltage drop of main bus	volt	v_b

Fortran	Description	Units	Algebraic
D(37)	instantaneous phase-c-to-ground voltage drop of main bus	volt	v_c
D(38)	instantaneous line-a-to-line-b voltage of main bus	volt	v_{ab}
D(39)	instantaneous line-b-to-line-c voltage of main bus	volt	v_{bc}
D(40)	instantaneous line-c-to-line-a voltage of main bus	volt	v_{ca}
D(41) to D(78)	not used		
D(79)	the expression	amp/sec	

$$\frac{(R_r + R_1)\, i_{1a} + R'_{\ell a} i_{\ell a}}{M_r + L_r + L_1} + \frac{(R'_{\ell a} + R_r + R'_2)\, i_{\ell a} - (R_r + R'_2)\, i_{1a}}{M_r + L_r + L'_2}$$

divided by the expression

$$1 - \frac{M_r}{M_r + L_r + L_1} - \frac{M_r}{M_r + L_r + L'_2}$$

Fortran	Description	Units	Algebraic
D(80)	same as D(79) with subscript a replaced by subscript b		
D(81)	same as D(79) with subscript a replaced by subscript c		
D(82)	$(2M_r + 2L_r + L_1 + L'_2)/[(L_r + L_1)(L_r + L'_2) - M_r^2]$	henry^{-1}	
D(83) to D(95)	not used		
D(96)	instantaneous voltage of phase A' of power source in commercial power system, referred to Y-connected secondary of interconnection transformer	volt	$e_{A'2}$
D(97)	same as D(96) but for phase B'	volt	$e_{B'2}$

Fortran	Description	Units	Algebraic
D(98)	same as D(96) but for phase C'	volt	$e_{C'2}$
D(99)	not used		
D(100) to D(111)	coefficients, pertaining to commercial power system, as indicated below		

$$\frac{di_a}{dt} = D(100) + D(101)\frac{di_{\ell a}}{dt} + D(102)\frac{di_{\ell b}}{dt} + D(103)\frac{di_{\ell c}}{dt}$$

$$\frac{di_b}{dt} = D(104) + D(105)\frac{di_{\ell a}}{dt} + D(106)\frac{di_{\ell b}}{dt} + D(107)\frac{di_{\ell c}}{dt}$$

$$\frac{di_c}{dt} = D(108) + D(109)\frac{di_{\ell a}}{dt} + D(110)\frac{di_{\ell b}}{dt} + D(111)\frac{di_{\ell c}}{dt}$$

D(112) to D(120)	not used		

G Array (in COMMON, Dimensions: 21 x 35)

Fortran	Description	Units	Algebraic
G(1,I)	time two integrating time steps back	sec	
G(2,I)	time one integrating time step back	sec	
G(3,I)	present time	sec	t
G(4,I)	value of B(7,I) for distribution transformers at time G(1,I)	volt	
G(5,I)	value of B(7,I) for distribution transformers at time G(2,I)	volt	
G(6,I)	value of B(7,I) for distribution transformers at time G(3,I)	volt	v_{AB}
G(7,I)	value of B(8,I) for distribution transformers at time G(1,I)	volt	
G(8,I)	value of B(8,I) for distribution transformers at time G(2,I)	volt	
G(9,I)	value of B(8,I) for distribution transformers at time G(3,I)	volt	v_{BC}
G(10,I)	value of B(9,I) for distribution transformers at time G(1,I)	volt	
G(11,I)	value of B(9,I) for distribution transformers at time G(2,I)	volt	
G(12,I)	value of B(9,I) for distribution transformers at time G(3,I)	volt	v_{CA}
G(13,I)	time of most recent zero-crossing of B(7,I) for distribution transformers	sec	
G(14,I)	time of most recent zero-crossing of B(8,I) for distribution transformers	sec	
G(15,I)	time of most recent zero-crossing of B(9,I) for distribution transformers	sec	
G(16,I)	used by VMAXTR as switch in computation of peaks of B(7,I) for distribution transformers		

Fortran	Description	Units	Algebraic
G(17,I)	same as G(16,I) but for B(8,I) for distribution transformers		
G(18,I)	same as G(16,I) but for B(9,I) for distribution transformers		
G(19,I)	used by VMAXTR as switch to skip computation of peaks and of frequency of B(7,I) for distribution transformers during a two-phase (A and B) or a three-phase (A, B and C) or a line-to-line (A to B) fault on secondary of distribution transformers		
G(20,I)	used by VMAXTR as switch to skip computation of peaks and of frequency of B(8,I) for distribution transformers during a three-phase (A, B and C) fault on secondary of distribution transformers		
G(21,I)	same as G(20,I) but for B(9,I) for distribution transformers		

L Array (in COMMON, Dimension: 134)

Fortran	Description	Units	Algebraic
L(1)	number of generating units		
L(2)	number of motor-generator sets		
L(3)	number of induction motors		
L(4)	number of distribution transformers		
L(5)	if L(5) 0, the commercial power system is connected to the power plant; otherwise, it is not		
L(6)	not used		
L(7)	describe type of fault on main bus <1, no fault =1, single phase (a) fault =2, two-phase (a and b) fault =3, three-phase (a, b and c) fault ≥4, line-to-line (a to b) fault		
L(8)	describe type of fault at primary side of commercial power interconnection transformer		
L(9)	frequency of output from PRINT2 in terms of integrating steps		
L(10)	frequency of output from PLØT2 in terms of integrating steps		
L(11) to L(25)	used by SAT and SATEF for field saturation effects of synchronous machines connected to main bus =1, corresponding machine is not saturated =2, corresponding machine is saturated		
L(26) to L(30)	not used		
L(31)	total number of dependent variables		
L(32)	used by SUB2 as switch to call INITIA		

Fortran	Description	Units	Algebraic
L(33)	used as switch to bypass YPRIM2; switch is set in SUB2		
L(34)	used as switch for calling PRINT2 from SUB2		
L(35)	used as switch for calling PLØT2 from SUB2		
L(36)	used as switch in SUB2 to back-step and integrate to zero current if necessary, when a component is being removed from main bus or a generator from the buses of the MG sets: switch is set in SWITCH and DISCØN		
L(37)	used as switch in SWITCH in conjunction with backstepping to integrate to zero phase-a-current when a component is being removed from the main bus		
L(38)	same as L(37) but for phase-b-current		
L(39)	same as L(37) but for phase-c-current		
L(40)	used as switch set by SWITCH: if L(40) is greater than zero, phase a of component being removed from main bus has been disconnected from main bus		
L(41)	same as L(40) but for phase b		
L(42)	same as L(40) but for phase c		
L(43)	identifies component being removed from main bus		
L(44)	number of records written by PLØT2		
L(45)	number of words per record written by PLØT2		
L(46)	used by VMAX as initializing switch		

Fortran	Description	Units	Algebraic
L(47)	not used		
L(48)	not used		
L(49)	number of input data cards with instructions for PLØT2		
L(50)	number of input data cards with instructions for PRINT2		
L(51) to L(86)	specify first entry in Y Array of dependent variables of each component		
L(87) to L(95)	used by SATG and SATEFG for field saturation effects of generators of MG sets		
L(96) to L(99)	not used		
L(100) to L(134)	specify type of components =1, for generating units =2, for motor-generator sets =3, for induction motors =4, for distribution transformers		

Y Array (in COMMON, Dimension: 316)

Generators of Generating Units

Fortran	Description	Units	Algebraic
Y(J)	instantaneous current of phase-a stator winding	amp	i_a
Y(J+1)	instantaneous current of phase-b stator winding	amp	i_b
Y(J+2)	instantaneous current of phase-c stator winding	amp	i_c
Y(J+3)	instantaneous current of field winding	amp	i_f
Y(J+4)	current of direct amortisseur winding	amp	i_d
Y(J+5)	current of quadrature amortisseur winding	amp	i_q
Y(J+6)	electrical angle of axis of field winding with respect to axis of phase-a stator winding, measured in direction of rotor's rotation	rad	θ
Y(J+7)	output voltage of regulator amplifier	volt	e_3
Y(J+8)	time integral, from time 0 to time t, of output voltage of feedback network in regulator	volt-sec	e'_4
Y(J+9)	output voltage of quadratic filter in terminal-voltage feedback loop of regulator	volt	e_2
Y(J+10)	time derivative of Y(J+9)	volt/sec	e'_2

Motor-Generator Sets

Motors

Fortran	Description	Units	Algebraic
Y(J)	instantaneous current of phase-a stator winding	amp	i_a
Y(J+1)	instantaneous current of phase-b stator winding	amp	i_b

Fortran	Description	Units	Algebraic
Y(J+2)	instantaneous current of phase-c stator winding	amp	i_c
Y(J+3)	instantaneous current of field winding	amp	i_f
Y(J+4)	current of direct amortisseur winding	amp	i_d
Y(J+5)	current of quadrature amortisseur winding	amp	i_q
Y(J+6)	electrical angle of axis of field winding with respect to axis of phase-a stator winding, measured in direction of rotor's rotation	rad	Θ
Y(J+7)	mechanical speed of rotor	rad/sec	ω_m
	Generators		
Y(J+8)	instantaneous current of phase-a stator winding	amp	i_a
Y(J+9)	instantaneous current of phase-b stator winding	amp	i_b
Y(J+10)	instantaneous current of phase-c stator winding	amp	i_c
Y(J+11)	instantaneous current of field winding	amp	i_f
Y(J+12)	current of direct amortisseur winding	amp	i_d
Y(J+13)	current of quadrature amortisseur winding	amp	i_q
Y(J+14)	electrical angle of axis of field winding with respect to axis of phase-a stator winding, measured in direction of rotor's rotation	rad	Θ
Y(J+15)	output voltage of regulator amplifier	volt	e_3
Y(J+16)	time integral, from time 0 to time t, of output voltage of feedback network in regulator	volt-sec	e'_4

Fortran	Description	Units	Algebraic
Y(J+17)	output voltage from quadratic filter in terminal-voltage feed-back loop of regulator	volt	e_2
Y(J+18)	time derivative of Y(J+17)	volt/sec	e'_2
	Induction Motors		
Y(J)	instantaneous current of phase-a stator winding	amp	i_a
Y(J+1)	instantaneous current of phase-b stator winding	amp	i_b
Y(J+2)	instantaneous current of phase-c stator winding	amp	i_c
Y(J+3)	instantaneous current of α rotor winding	amp	i_α
Y(J+4)	instantaneous current of β rotor winding	amp	i_β
Y(J+5)	electrical angle of axis of α rotor winding with respect to axis of phase-a stator winding, measured in direction of rotor's rotation	rad	Θ
Y(J+6)	mechanical speed of rotor	rad/sec	ω_m
	Distribution Transformers		
Y(J)	instantaneous current of phase-A secondary winding	amp	i_A
Y(J+1)	instantaneous current of phase-B secondary winding	amp	i_B
Y(J+2)	instantaneous current of phase-C secondary winding	amp	i_C
	Commercial Power System		
Y(J)	instantaneous current to phase a of main bus	amp	i_a
Y(J+1)	instantaneous current to phase b of main bus	amp	i_b

Fortran	Description	Units	Algebraic
Y(J+2)	instantaneous current to phase c of main bus	amp	i_c

APPENDIX C

FORTRAN LISTING OF MAIN SPEED AND MAIN TORQUE AND SUB2 PROGRAMS

(pages 94 to 176)

```
      SUBROUTINE SPEED
C     MAIN PROGRAM WITH CONSTANT SPEED MODELS FOR PRIME MOVERS OF GENE-
C     RATING UNITS.
      COMMON DSUB2
      DIMENSION DSUB2(13271)
      DIMENSION SP(10),TOR(10),XLOAD(10),TITLE(13)
  995 FORMAT(I5)
  996 FORMAT(13A6)
  997 FORMAT(1H1,47HINPUT DATA FOR PRIME MOVERS OF GENERATING UNITS//1H
     1,13A6)
  998 FORMAT(2E10.3)
  999 FORMAT(1H0,6HSPEED=,F8.4/1H ,16HDURATION OF RUN=,F8.4,4H SEC)
      READ(5,995)  N
    2 READ (5,996) TITLE
      WRITE (6,997) TITLE
      READ(5,998) XT,SPE
      WRITE(6,999) SPE,XT
      CALL INPUT2
      DO  1  I=1,10
    1 SP(I)=SPE
      X=0.0
      CALL SUB2(X,SP,TOR,XLOAD,FR,NT)
      CALL PRINT2
      X=XT
      CALL SUB2(X,SP,TOR,XLOAD,FR,NT)
      CALL PRINT2
      CALL PRINTO
      CALL TAPE2
      N=N-1
      IF(N)3,3,2
    3 CALL EXIT
      END
```

```
      SUBROUTINE TORQUE
C     MAIN PROGRAM WITH CONSTANT TORQUE MODELS FOR PRIME MOVERS OF GENE-
C     RATING UNITS.
C     SUBROUTINES RNGKTA AND YPRIME INTEGRATE THE EQUATIONS OF MOTION OF
C     THE SHAFTS OF THE GENERATING UNITS USING CONSTANT MECHANICAL TOR-
C     QUE. THE DEPENDENT VARIABLES ARE THE SHAFT SPEEDS.
      COMMON DSUB2
      DIMENSION DSUB2(13271)
      COMMON X,Y,F,Q,A,B,C,L
      DIMENSION Y(10),F(10),Q(10),A(10),B(20),C(2),L(2)
      DIMENSION SP(10),TOR(10),XLOAD(10),TITLE(13)
  100 FORMAT(I5)
  101 FORMAT(13A6)
  102 FORMAT(I5,2E10.4)
  103 FORMAT(3E10.4)
  104 FORMAT (1H1,47HINPUT DATA FOR PRIME MOVERS OF GENERATING UNITS//1H
     1 ,13A6)
  105 FORMAT(1H0,7X,5HSPEED,10X,6HTORQUE,10X,7HINERTIA/)
  106 FORMAT(3(3X,E13.6))
  107 FORMAT(1H0,17HINTEGRATING STEP=,F7.4,4H SEC/1H ,16HDURATION OF RUN
     1=,F8.4,4H SEC)
      READ (5,100) N
    1 READ (5,101) TITLE
      WRITE (6,104) TITLE
      READ (5,102) L(1),C(1),C(2)
      L1=L(1)
      DO 2 I=1,L1
    2 READ (5,103) Y(I),B(I),A(I)
      WRITE (6,105)
      DO 3 I=1,L1
    3 WRITE (6,106) Y(I),B(I),A(I)
      WRITE (6,107) C(1),C(2)
      CALL INPUT2
      DO 4 I=1,L1
    4 SP(I)=Y(I)
      X=0.0
      L(2)=0
      CALL SUB2(X,SP,TOR,XLOAD,FR,NT)
      L(1)=NT
      CALL PRINT2
    5 IF(X-C(2)) 6,10,10
    6 IF(X-C(2)+C(1)) 8,7,7
    7 C(1)=C(2)-X
      IDX=2
      GO TO 9
    8 IDX=1
    9 CALL RNGKTA
      GO TO (5,10),IDX
   10 L1=L(1)
      DO 11 I=1,L1
   11 SP(I)=Y(I)
      CALL SUB2(X,SP,TOR,XLOAD,FR,NT)
      CALL PRINT2
      CALL PRINTO
      CALL TAPE2
      N=N-1
      IF(N) 12,12,1
   12 CALL EXIT
      END
```

```
      SUBROUTINE RNGKTA
C     INTEGRATION SCHEME FOR SHAFT SPEEDS OF GENERATING UNITS--GILL PRO-
C     CEDURE OF THE FOURTH ORDER RUNGE-KUTTA METHOD.
      COMMON DSUB2
      DIMENSION DSUB2(13271)
      COMMON X,Y,F,Q,A,B,C,L
      DIMENSION Y(10),F(10),Q(10),A(10),B(20),C(2),L(2)
      N=L(1)
      IF(L(2)) 4,4,1
    4 L(2)=10
      DO 3 I=1,N
    3 Q(I)=0.0
    1 H=C(1)
      HH=.5*H
      CALL YPRIME
      DO 5 I=1,N
      S=F(I)*H
      T=.5*(S-2.*Q(I))
      Y(I)=Y(I)+T
    5 Q(I)=Q(I)+3.*T-.5*S
      X=X+HH
      CALL YPRIME
      DO 6 I=1,N
      S=F(I)*H
      T=.29289322*(S-Q(I))
      Y(I)=Y(I)+T
    6 Q(I)=Q(I)+3.*T -.29289322*S
      CALL YPRIME
      DO 7 I=1,N
      S=F(I)*H
      T=1.7071067*(S-Q(I))
      Y(I)=Y(I)+T
    7 Q(I)=Q(I)+3.*T-1.707106*S
      X=X+HH
      CALL YPRIME
      DO 8 I=1,N
      S=F(I)*H
      T=(S-2.*Q(I))/6.
      Y(I)=Y(I)+T
    8 Q(I)=Q(I)+3.*T-.5*S
      RETURN
      END
```

```
      SUBROUTINE YPRIME
C     EVALUATION OF DERIVATIVES OF SHAFT SPEEDS OF GENERATING UNITS.
      COMMON DSUB2
      DIMENSION DSUB2(13271)
      COMMON X,Y,F,Q,A,B,C,L
      DIMENSION Y(10),F(10),Q(10),A(10),B(20),C(2),L(2)
      DIMENSION SP(10),TOR(10),XLOAD(10)
      L1=L(1)
      DO 10 I=1,L1
   10 SP(I) = Y(I)
      CALL SUB2(X,SP,TOR,XLOAD,FR,NT)
      L(1)=NT
      L1=L(1)
      DO 20 I=1,L1
      B(I+10) = TOR(I)
   20 F(I)=32.174*(B(I)-B(I+10))/A(I)
      RETURN
      END
```

```
      SUBROUTINE SUB2(XA,SP,TOR,XLOAD,FR,NS)
C     SUBROUTINES SUB2,INPUT2,SETF,SETI,PRINT2,PLOT2,TAPE2,PRINTO,
C     INITIA,RNGKT2,SWITCH,DISCON,VMAX,VMAXGB,TRAN,VMAXTR,DUPLEX,VMAXDR,
C     YPRIM2,LMAT,IMAT,SAT,SATEF,RLMB,XLMAT,TRIAS,CDMACH,CDTRAN,CDCOMP,
C     CDDR,MBSOLV,FMACH,FTRAN,FCOMP,FDR,FREG,YPRIMG,LMATG,IMATG,SATG,
C     SATEFG,RLGB,XMMAT,TRIAG,GBMAT,GBSOLV,FGEN,FREGG,FMECH AND TORIM
C     CONSTITUTE A SUBSYSTEM(SUB2) OF THE OVERALL POWER PLANT.
C     THEY HAVE THE SAME COMMON, EXCEPT FOR SETF AND SETI WHICH HAVE NO
C     COMMON.
C     THEY HANDLE ALL COMPONENTS OF THE POWER PLANT EXCEPT THE PRIME MO-
C     VERS OF THE GENERATING UNITS AND THEIR FUEL CONTROLS.
C     FOR GIVEN SHAFT SPEEDS(SP) OF THE GENERATING UNITS, INTEGRATE THE
C     EQUATIONS OF SUB2 FROM SUB2 TIME X TO MAIN TIME XA.
C     AT TIME XA, TRANSFER TO MAIN THE EM TORQUES(TOR) AND THE AVERAGE
C     THREE-PHASE POWERS(LOAD) OF THE GENERATING UNITS, AND THE FREQUEN-
C     CY(FR) OF THE MAIN BUS. THE NUMBER OF GENERATING UNITS CONNECTED
C     TO THE MAIN BUS AT TIME XA IS NS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(50
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      DIMENSION SP(10),TOR(10),XLOAD(10)
      IF(L(32)) 2,1,2
    1 CALL INITIA
      L(32)=10
    2 NS=L(1)
      NT=L(1)+L(2)+L(3)
      IF(NS.LE.0) GO TO 401
C     TO 3--, COMPUTE THE ELECTRICAL SPEEDS AND THE PERCENT SPEED ERRORS
C     OF THE GENERATING UNITS.
      DO 3 I=1,NS
      B(5,I)=A(15,I)*SP(I)
    3 B(4,I) = 100.0*(B(5,I)/377.0-1.0)
  401 II=1
    4 IF(XA-X-0.001*C(1)) 32,32,5
C     TO 12--, INTEGRATE.
    5 IF(XA-X-C(1)) 6,6,7
    6 D(31)=XA-X
      IDX=1
      GO TO 11
    7 D(31)=C(1)
      IDX=2
   11 SW=0.0
   12 CALL RNGKT2
      IF(SW.GT.0.0) GO TO 520
C     TO 520--, DISCONNECT COMPONENTS FROM THE MAIN BUS.
      IF(L(4).LE.0) GO TO 510
      N1=NT+1
      N2=N1+L(4)-1
      DO 500 I=N1,N2
      J=L(I+50)
      B(1,I)=(Y(J+2)-Y(J))/A(3,I)
      B(2,I)=(Y(J)-Y(J+1))/A(3,I)
  500 B(3,I)=(Y(J+1)-Y(J+2))/A(3,I)
  510 CALL SWITCH
      ISX=L(36)
      GO TO (520,12),ISX
```

```
  520 SW=10.0
C     TO 530--, DISCONNECT GENERATORS FROM THE BUSES OF THE MG SETS.
      IF(L(2).LE.0) GO TO 530
      CALL DISCON
      ISX=L(36)
      GO TO (530,12),ISX
  530 NT=L(1)+L(2)+L(3)
      NS=L(1)
      IF(NT.LE.0) GO TO 409
C     TO 18--, CONVERT THE ELECTRICAL ANGLES OF ROTATING MACHINES TO AN-
C     GLES LESS THAN 2PI RADIANS.
      DO 18 I=1,NT
      LI=L(I+99)
      GO TO (14,13,15),LI
   13 J=L(I+50)+14
      IF(Y(J).GT.6.283185307) Y(J)=Y(J)-6.283185307
   14 J=L(I+50)+6
      GO TO 16
   15 J=L(I+50)+5
   16 IF(Y(J).GT.6.283185307) Y(J)=Y(J)-6.283185307
   18 CONTINUE
C     TO 407--, COMPUTE THE PERCENT ERRORS OF THE PEAKS AND FREQUENCIES
C     OF THE LINE-TO-LINE VOLTAGES AT VARIOUS POINTS OF THE POWER PLANT.
  409 CALL YPRIM2
      L(33)=10
      CALL VMAX
      IF(L(2).GT.0) CALL VMAXGB
      IF ( L(4) .LE. 0 ) GO TO 408
      CALL TRAN
      CALL VMAXTR
  408 IF(L(6).LE.0) GO TO 407
      CALL DUPLEX
      CALL VMAXDR
  407 IF(L(34)) 21,19,21
C     TO 402--, OUTPUT FROM PRINT2.
   19 L(34)=L(9)-1
      IPP=1
  404 IF(NT.LE.0) GO TO 410
C     TO 20--, COMPUTE THE EM TORQUES OF GENERATING UNITS, AND THE AVE-
C     RAGE 3-PHASE POWERS AND PEAK REACTIVE POWERS PER PHASE OF MOTORS.
      DO 20 I=1,NT
      J=L(I+50)
      J2=J+1
      J3=J2+1
      LI=L(I+99)
      GO TO (406,405,405),LI
  405 B(1,I)=-0.001*(D(35)*Y(J)+D(36)*Y(J2)+D(37)*Y(J3))
      B(2,I)=-1.9245E-4*(Y(J)*D(39)+Y(J2)*D(40)+Y(J3)*D(38))
      GO TO 20
  406 B(3,I)=(A(4,I)*(Y(J+3)-B(7,I))+A(5,I)*Y(J+4))*(Y(J)*B(20,I)+Y(J2)*
     1B(24,I)+Y(J3)*B(22,I))+A(6,I)*Y(J+5)*(Y(J)*B(19,I)+Y(J2)*B(23,I)+Y
     2(J3)*B(21,I))
      IF(A(3,I)) 103,103,101
  101 B(3,I)=B(3,I)-A(3,I)*(B(26,I)*(Y(J)*Y(J)+2.0*Y(J3)*Y(J2))+B(28,I)*
     1(Y(J2)*Y(J2)+2.0*Y(J)*Y(J3))+B(30,I)*(Y(J3)*Y(J3)+2.0*Y(J)*Y(J2)))
  103 B(3,I)=-0.737564*A(15,I)*B(3,I)
   20 CONTINUE
  410 GO TO (402,27,36),IPP
  402 CALL PRINT2
```

```
      IP=1
      GO TO 22
   21 IP=2
      L(34)=L(34)-1
   22 IF (X - 0.017) 29,23,23
   23 IF(L(35)) 28,24,28
C     TO 27--, OUTPUT FROM PLOT2.
   24 L(35)=L(10)-1
      GO TO (27,25),IP
   25 CONTINUE
      IPP=2
      GO TO 404
   27 CALL PLOT2
      GO TO 29
   28 L(35)=L(35)-1
   29 GO TO (30,31),IDX
   30 L(33)=0
      GO TO (36,34),IP
   31 II=2
      GO TO 4
   32 GO TO (33,30),II
C     TO 36--, COMPUTE ALL THE VARIABLES OF SUB2 WHEN XA>X.
   33 CALL YPRIM2
      IF(L(4).GT.0) CALL TRAN
      IF(L(6).GT.0) CALL DUPLEX
   34 IPP=3
      GO TO 404
   36 CONTINUE
      IF(NS.LE.0) GO TO 403
C     TO 403--, COMPUTE TOR, XLOAD AND FR.
      DO 37 I=1,NS
      TOR(I)=B(3,I)
   37 XLOAD(I)=B(1,I)
  403 FR = 60.0*(D(2) + 1.0)
      RETURN
      END
```

```
      SUBROUTINE INPUT2
C     READ INPUT DATA FOR SUB2
C     ALL COMMON, EXCEPT TITLE AND HEAD, IS INITIALIZED TO ZERO BEFORE
C     DATA ARE READ.
C     DATA ARE CHECKED FOR ERRORS AS THEY ARE READ. THE RUN IS ABORTED
C     WITH THE FIRST ERROR FOUND, AND A COMMENT IS WRITTEN IN TAPE 6.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      DIMENSION E(6),N(10),BB(8)
      DATA BB/1HX,1HY,1HF,1HL,1HC,1HD,1HA,1HB/,
     1N/1,316,316,134,50,120,80,99,35/,
     2BR,BI,BP,BG/1HR,1HI,1HP,1HG/
  100 FORMAT(13A6)
  101 FORMAT (1H1,19HINPUT DATA FOR SUB2//1H ,13A6/1H ,13A6/1H ,13A6)
  102 FORMAT(1H ,13A6/1H ,13A6/1H ,13A6)
  103 FORMAT(A1,1X,A1,7I1,6E10.4)
  104 FORMAT(1H1,25HABNORMAL EXIT FROM INPUT2/9H BAD DATA/1H ,A1,1X,A1,7
     1I1)
  105 FORMAT(1H ,A1,1X,A1,1H(,I3,1H-,I3,1H),6X,6E17.6)
  106 FORMAT(1H ,A1,1X,A1,1H(,I2,1H-,I2,1H,,I2,1H),5X,6E17.6)
  107 FORMAT (1H ,A1,1X,A1,1H(,I3,1H-,I3,1H))
  108 FORMAT (1H ,A1,1X,A1,1H(,I2,1H-,I2,1H,,I2,1H))
  109 FORMAT (1H1,6HOUTPUT//1H ,13A6/1H ,13A6/1H ,13A6)
C     TWO LINES DOWN--, INITIALIZE COMMON.
      CALL SETF(A,12759,0.0)
      CALL SETI(L,434,0)
      M=0
      K=0
      DO 45 I=1,8
   45 BO(I) = BB(I)
      READ (5,100) TITLE
      WRITE (6,101) TITLE
      READ (5,100) HEAD
      WRITE (6,102) HEAD
    2 READ (5,103) C1,C2,I1,I2,I3,I4,I5,I6,I7,E
      IF (C1 - BR) 3,40,3
    3 DO 4 I=1,8
      II=I
      IF(C2-BO(I))4,6,4
    4 CONTINUE
C     BAD DATA. ABORT RUN.
    5 WRITE (6,104) C1,C2,I1,I2,I3,I4,I5,I6,I7
      CALL EXIT
    6 GO TO (7,7,7,7,7,7,8,8),II
    7 K1=100*I1+10*I2+I3
      K2=100*I5+10*I6+I7
      K3=0
      GO TO 10
    8 K1=10*I3+I4
      K2=10*I6+I7
      K3=10*I1+I2
      IF (K3 - N(9)) 10,10,5
   10 K4=K2-K1+1
      IF(K2-N(II)) 11,11,5
   11 IF(K1) 5,5,12
```

```
12 IF(K2-K1) 5,13,13
13 IF(C1-BI) 33,14,33
14 IF(K4-6) 15,15,5
15 GO TO (16,16,16,16,16,16,28,28),II
16 WRITE (6,105) C1,C2,K1,K2,(E(I),I=1,K4)
   GO TO (17,18,20,22,24,26),II
17 X=E(1)
   GO TO 2
18 DO 19 I=1,K4
   J=K1+I-1
19 Y(J)=E(I)
   GO TO 2
20 DO 21 I=1,K4
   J=K1+I-1
21 F(J)=E(I)
   GO TO 2
22 DO 23 I=1,K4
   J=K1+I-1
23 L(J)=E(I)
   GO TO 2
24 DO 25 I=1,K4
   J=K1+I-1
25 C(J)=E(I)
   GO TO 2
26 DO 27 I=1,K4
   J=K1+I-1
27 D(J)=E(I)
   GO TO 2
28 WRITE (6,106) C1,C2,K1,K2,K3,(E(I),I=1,K4)
   IF(II-7) 29,29,31
29 DO 30 I=1,K4
   J=K1+I-1
30 A(J,K3)=E(I)
   GO TO 2
31 DO 32 I=1,K4
   J=K1+I-1
32 B(J,K3)=E(I)
   GO TO 2
33 IF(C1-BP) 35,34,35
34 M=M+1
   EP(M)=C2
   LP1(M)=K1
   LP2(M)=K2
   LP3(M)=K3
   GO TO 37
35 IF(C1-BG) 5,36,5
36 K=K+1
   EG(K)=C2
   LG1(K)=K1
   LG2(K)=K2
   LG3(K)=K3
37 IF (II - 6) 38,38,39
38 WRITE (6,107) C1,C2,K1,K2
   GO TO 2
39 WRITE (6,108) C1,C2,K1,K2,K3
   GO TO 2
40 L(50)=M
   L(49)=K
   WRITE (6,109) TITLE
```

```
      RETURN                                                    02 0118
      END                                                       02 0119
```

```
      SUBROUTINE SETF (AI,J,AK)
C     SET J POSITIONS OF REAL ARRAY AI TO THE VALUE AK.
      DIMENSION AI(1)
      DO 10 IJ=1,J
      AI(IJ) = AK
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SETI(II,J,K)
C     SET J POSITIONS OF INTEGER ARRAY II TO THE VALUE K.
      DIMENSION II(1)
      DO 10 IJ=1,J
      II(IJ) = K
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PRINT2
C     OUTPUT FOR SUB2 ON TAPE 6.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE, HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
  100 FORMAT (1H0)
  101 FORMAT(1H ,A1,1H(,I3,1H-,I3,1H),2X,10(1PE12.4))
  102 FORMAT(1H ,A1,1H(,I2,1H-,I2,1H,,I2,1H),1X,10(1PE12.4))
  103 FORMAT(1H ,A1,1H(,I3,1H-,I3,1H),2X,10I6)
      M=L(50)
      IF(M) 19,19,1
    1 WRITE (6,100)
      DO 18 I=1,M
      DO 2 J=1,8
      JJ=J
      IF(EP(I)-BO(J)) 2,3,2
    2 CONTINUE
    3 K1=LP1(I)
      K2=LP2(I)
      K3=LP3(I)
    4 IF(K2-K1) 18,6,5
    5 IF(K2-K1-9) 6,6,7
    6 K4=K2
      GO TO 8
    7 K4=K1+9
    8 GO TO (9,10,11,12,13,14,15,16),JJ
    9 WRITE (6,101) BO(JJ),K1,K4,X
      GO TO 17
   10 WRITE (6,101) BO(JJ),K1,K4,(Y(J),J=K1,K4)
      GO TO 17
   11 WRITE (6,101) BO(JJ),K1,K4,(F(J),J=K1,K4)
      GO TO 17
   12 WRITE (6,103) BO(JJ),K1,K4,(L(J),J=K1,K4)
      GO TO 17
   13 WRITE (6,101) BO(JJ),K1,K4,(C(J),J=K1,K4)
      GO TO 17
   14 WRITE (6,101) BO(JJ),K1,K4,(D(J),J=K1,K4)
      GO TO 17
   15 WRITE (6,102) BO(JJ),K1,K4,K3,(A(J,K3),J=K1,K4)
      GO TO 17
   16 WRITE (6,102) BO(JJ),K1,K4,K3,(B(J,K3),J=K1,K4)
   17 K1=K1+10
      GO TO 4
   18 CONTINUE
   19 RETURN
      END
```

```
      SUBROUTINE PLOT2
C     OUTPUT FOR SUB2 ON TAPE 2.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(50
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      DIMENSION P(50)
      K=L(49)
      IF(K) 20,20,1
    1 L(44)=L(44)+1
      I=0
      DO 19 J=1,K
      DO 2 M=1,8
      MM=M
      IF(EG(J)-BO(M)) 2,3,2
    2 CONTINUE
    3 K1=LG1(J)
      K2=LG2(J)
      K3=LG3(J)
      GO TO (4,5,7,9,11,13,15,17),MM
    4 I=I+1
      P(I)=X
      GO TO 19
    5 DO 6 N=K1,K2
      I=I+1
    6 P(I)=Y(N)
      GO TO 19
    7 DO 8 N=K1,K2
      I=I+1
    8 P(I)=F(N)
      GO TO 19
    9 DO 10 N=K1,K2
      I=I+1
   10 P(I)=L(N)
      GO TO 19
   11 DO 12 N=K1,K2
      I=I+1
   12 P(I)=C(N)
      GO TO 19
   13 DO 14 N=K1,K2
      I=I+1
   14 P(I)=D(N)
      GO TO 19
   15 DO 16 N=K1,K2
      I=I+1
   16 P(I)=A(N,K3)
      GO TO 19
   17 DO 18 N=K1,K2
      I=I+1
   18 P(I)=B(N,K3)
   19 CONTINUE
      L(45)=I
      WRITE (2) (P(J),J=1,I)
   20 RETURN
      END
```

```
      SUBROUTINE TAPE2
C     TRANSFER TO TAPES 6 AND 7 THE OUTPUT WRITTEN BY PLOT2 ON TAPE 2.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(50
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      DIMENSION P(50)
  100 FORMAT(1H1,18HPRINTOUT OF TAPE 7/1H ,13A6/1H ,13A6/1H ,13A6)
  101 FORMAT(1H ,13A6/1H ,13A6/1H ,13A6)
  102 FORMAT(1H ,18HNUMBER OF RECORDS=,I4)
  103 FORMAT (1H ,7(1PE15.4),2I6)
  104 FORMAT(13A6)
  105 FORMAT(18HNUMBER OF RECORDS=,I4)
  106 FORMAT(7(1PE10.3),2I5)
      IF(L(44)) 8,8,1
    1 WRITE (6,100) TITLE
      WRITE (6,101) HEAD
      WRITE (6,102) L(44)
      WRITE (7,104) TITLE
      WRITE (7,104) HEAD
      WRITE (7,105) L(44)
      REWIND 2
      II=L(44)
      KK=L(45)
      DO 3 I=1,50
    3 P(I) = 0.0
      DO 7 I=1,II
      READ(2) (P(K),K=1,KK)
      J=1
      K1=1
      K2=7
    5 WRITE (6,103) (P(K),K=K1,K2),I,J
      WRITE (7,106) (P(K),K=K1,K2),I,J
      IF(K2-KK) 6,7,7
    6 K1=K1+7
      K2=K2+7
      J=J+1
      GO TO 5
    7 CONTINUE
    8 RETURN
      END
```

```
      SUBROUTINE PRINTO
C     WRITE ON TAPE 6 THE VALUES OF THE DEPENDENT AND OTHER VARIABLES OF
C     SUB2.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(50
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
    1 FORMAT(1H1,47HVALUES OF DEPENDENT AND OTHER VARIABLES AT TIME,F9.4
     1,4H SEC/1H0)
    2 FORMAT(1H0,12H SET NUMBER ,I2/)
    3 FORMAT(1H ,2HY(,I3,3H) =,E16.8)
   11 FORMAT(1H0,24H COMMERCIAL POWER SYSTEM/)
   14 FORMAT (1H ,2HB(,I2,1H,,I2,2H)=,E16.8/3H F(,I3
     1,2H)=,E16.8/)
   16 FORMAT(1H0,47H DUPLEX REACTOR AND HIGH VOLTAGE POWER SUPPLIES/)
      WRITE(6,1) X
      NS=L(1)+L(2)+L(3)+L(4)
      N1=1
      N2=0
      IF ( NS .LE. 0 ) GO TO 111
      DO 5 I=1,NS
      WRITE(6,2) I
      LI=L(I+99)
      GO TO (6,7,8,18),LI
    6 N2=N2+11
      J=14
      J9 = N1+8
      WRITE (6,14) J,I,B(J,I),J9,F(J9)
      GO TO 9
    7 N2=N2+19
      J9=N1+16
      J=42
      WRITE(6,14) J,I,B(J,I),J9,F(J9)
      GO TO 9
    8 N2=N2+7
      GO TO 9
   18 N2=N2+3
    9 DO 4 J=N1,N2
    4 WRITE(6,3) J,Y(J)
    5 N1=N2+1
  111 IF ( L(5) ) 13, 13, 10
   10 WRITE (6,11)
      N2=N2+3
      DO 12  J=N1,N2
   12 WRITE (6,3) J,Y(J)
   13 IF (L(6).LE.0) GO TO 15
      WRITE (6,16)
      N2=L(31)
      DO 17 J=N1,N2
   17 WRITE (6,3) J,Y(J)
   15 RETURN
      END
```

```
      SUBROUTINE INITIA
C     INITIALIZE CERTAIN VARIABLES AND CONSTANTS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      REWIND 2
      NS=L(1)+L(2)+L(3)+L(4)
      L(34) = L(9)-1
      L(35) = L(10)-1
      L(31)=11*L(1)+19*L(2)+7*L(3)+3*L(4)
      IF(L(5).LE.0) GO TO 1
      L(31)=L(31)+3
      L(NS+51) = L(31) - 2
    1 IF(L(6).LE.0) GO TO 2
      L(31)=L(31)+6
    2 IF(NS.LE.0) RETURN
      J=1
      DO 9 I=1,NS
      L(I+50) = J
      LI=L(I+99)
      GO TO (4,5,7,10),LI
    4 A(36,I)=B(14,I)
      A(37,I)=F(J+8)
      J=J+11
      GO TO 6
    5 A(66,I)=B(42,I)
      A(67,I)=F(J+16)
      J=J+19
      K=I-L(1)
      XM(6,6,K)=A(40,I)
      W(4,4,K)=A(42,I)
      W(5,5,K)=A(43,I)
      W(6,6,K)=A(44,I)
    6 XL(6,6,I)=A(10,I)
      Z(4,4,I)=A(12,I)
      Z(5,5,I)=A(13,I)
      Z(6,6,I)=A(14,I)
      GO TO 9
    7 XL(5,5,I)=A(3,I)
      Z(1,1,I) = A(5,I)
      Z(2,2,I) = A(5,I)
      Z(3,3,I) = A(5,I)
      Z(4,4,I) = A(6,I)
      Z(5,5,I)=A(6,I)
      J=J+7
      GO TO 9
   10 J=J+3
    9 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE RNGKT2
C     INTEGRATION SCHEME FOR THE DEPENDENT VARIABLES OF SUB2--GILL PRO-
C     CEDURE OF THE FOURTH ORDER RUNGE-KUTTA METHOD.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      N=L(31)
      H=D(31)
      HH=.5*H
      CALL YPRIM2
      DO 5 I=1,N
      S=F(I)*H
      T=.5*(S-2.*Q(I))
      Y(I)=Y(I)+T
    5 Q(I)=Q(I)+3.*T-.5*S
      X=X+HH
      CALL YPRIM2
      DO 6 I=1,N
      S=F(I)*H
      T=0.292893219*(S-Q(I))
      Y(I)=Y(I)+T
    6 Q(I)=Q(I)+3.*T -0.292893219*S
      CALL YPRIM2
      DO 7 I=1,N
      S=F(I)*H
      T=1.707106781*(S-Q(I))
      Y(I)=Y(I)+T
    7 Q(I)=Q(I)+3.0*T-1.707106781*S
      X=X+HH
      CALL YPRIM2
      DO 8 I=1,N
      S=F(I)*H
      T=(S-2.*Q(I))/6.
      Y(I)=Y(I)+T
    8 Q(I)=Q(I)+3.*T-.5*S
      RETURN
      END
```

```
      SUBROUTINE SWITCH
C     DISCONNECT COMPONENTS FROM THE MAIN BUS PHASE-BY-PHASE WHEN THE
C     RESPECTIVE PHASE CURRENTS ARE ZERO.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      DIMENSION YY(316),QQ(316),BB(3,35)
      IF(L(37).LE.0) GO TO 3
      L(37)=0
C     DISCONNECT PHASE A.
    2 L(40)=10
      IF(I.GT.NS.OR.LI.NE.4) GO TO 50
      N=J+2
    1 Y(J)=0.5*(Y(J)+Y(N))
      Q(J)=0.5*(Q(J)+Q(N))
      Y(N)=Y(J)
      Q(N)=Q(J)
      GO TO 55
    3 IF(L(38).LE.0) GO TO 6
      L(38)=0
C     DISCONNECT PHASE B.
    5 L(41)=10
    4 IF(I.GT.NS.OR.LI.NE.4) GO TO 50
      N=J-1
      GO TO 1
    6 IF(L(39).LE.0) GO TO 10
      L(39)=0
C     DISCONNECT PHASE C.
    9 L(42)=10
      GO TO 4
   10 NS=L(1)+L(2)+L(3)+L(4)
C     TO 20--, DETERMINE COMPONENT TO BE DISCONNECTED.
      IF(NS.LE.0) GO TO 15
      DO 13 I=1,NS
      XD=A(20,I)
      LI=L(I+99)
      IF(LI.EQ.3) XD=A(8,I)
      IF(LI.EQ.4) XD=A(11,I)
      IF(X.LT.XD) GO TO 13
      L(43)=I
      GO TO 20
   13 CONTINUE
   15 IF(L(5).LE.0) GO TO 200
      IF(X.LT.C(46)) GO TO 200
      L(43)=NS+1
   20 I=L(43)
   25 IF(L(40).GT.0) GO TO 35
C     TO ABOVE 26--, DETERMINE IF PHASE A SHOULD BE DISCONNECTED.
      J=L(I+50)
      PY=Y(J)*YY(J)
      IF(I.LE.NS.AND.LI.EQ.4) PY=B(1,I)*BB(1,I)
      K=1
      IF(PY) 26,2,35
   26 L(37) = 10
C     TO 30--, BACKSTEP TO INTEGRATE TO ZERO CURRENT.
   27 RY=YY(J)/(YY(J)-Y(J))
```

```
      IF(I.LE.NS.AND.LI.EQ.4) RY=BB(K,I)/(BB(K,I)-B(K,I))
      X=X-D(31)
      D(31)=D(31)*RY
      L(36)=2
      NN=L(31)
      DO 30 N=1,NN
      Y(N)=YY(N)
   30 Q(N)=QQ(N)
      RETURN
   35 IF(L(41).GT.0) GO TO 40
C     TO ABOVE 38--, DETERMINE IF PHASE B SHOULD BE DISCONNECTED.
      J=L(I+50)+1
      PY=Y(J)*YY(J)
      IF(I.LE.NS.AND.LI.EQ.4) PY=B(2,I)*BB(2,I)
      K=2
      IF(PY) 38,5,40
   38 L(38) = 10
      GO TO 27
   40 IF(L(42).GT.0) GO TO 200
C     TO ABOVE 45--, DETERMINE IF PHASE C SHOULD BE DISCONNECTED.
      J=L(I+50)+2
      PY=Y(J)*YY(J)
      IF(I.LE.NS.AND.LI.EQ.4) PY=B(3,I)*BB(3,I)
      K=3
      IF(PY) 45,9,200
   45 L(39) = 10
      GO TO 27
   50 Y(J)=0.0
      Q(J)=0.0
C     TO ABOVE 60--, DETERMINE IF ALL PHASES ARE DISCONNECTED.
      IF(L(40).GT.0.AND.L(41).GT.0.AND.L(42).GT.0) GO TO 60
      GO TO 25
   55 IF(L(40).GT.0.AND.L(41).GT.0) GO TO 60
      IF(L(40).GT.0.AND.L(42).GT.0) GO TO 60
      IF(L(41).GT.0.AND.L(42).GT.0) GO TO 60
      GO TO 25
C     TO 180--, COMPONENT HAS BEEN DISCONNECTED. ADJUST VARIABLES AND
C     SHIFT ARRAYS. ALSO, SHIFT INSTRUCTIONS FOR PLOT2.
   60 L(40)=0
      L(41)=0
      L(42)=0
      L(43)=0
      IF(I.LE.NS) GO TO 70
      L(5)=0
      K=3
      IF(L(6)) 160,160,140
   70 GO TO (80,90,100,110),LI
   80 L(1)=L(1)-1
      K=11
      GO TO 120
   90 L(2)=L(2)-1
      K=19
      IF(I.EQ.NS) GO TO 120
      J1=I-L(1)
      J2=L(2)
      IF(J1.GT.J2) GO TO 120
      DO 98 J=J1,J2
      J3=J+1
      DO 92 N=1,21
```

```
   92 VV(N,J)=VV(N,J3)
      DO 96 M=1,6
      DO 94 N=1,6
   94 W(M,N,J)=W(M,N,J3)
      DO 95 N=1,10
   95 XM(M,N,J)=XM(M,N,J3)
   96 CONTINUE
   98 CONTINUE
      GO TO 120
  100 L(3)=L(3)-1
      K=7
      GO TO 120
  110 L(4)=L(4)-1
      K=3
  120 IF(I.EQ.NS) GO TO 130
      J1=I
      J2=NS-1
      DO 129 J=J1,J2
      J3=J+1
      DO 121 M=1,80
  121 A(M,J)=A(M,J3)
      DO 122 M=1,99
  122 B(M,J)=B(M,J3)
      IF(L(J+99).EQ.4) GO TO 126
      DO 125 M=1,6
      DO 123 N=1,6
  123 Z(M,N,J)=Z(M,N,J3)
      DO 124 N=1,10
  124 XL(M,N,J)=XL(M,N,J3)
  125 CONTINUE
      GO TO 128
  126 DO 127 M=1,21
  127 G(M,J)=G(M,J3)
  128 L(J+99)=L(J3+99)
      L(J+50)=L(J3+50)-K
  129 CONTINUE
  130 IF(L(5).GT.0) GO TO 135
      IF(I-NS) 140,160,140
  135 L(NS+50)=L(NS+51)-K
  140 J1=L(I+50)+K
      J2=L(31)
      DO 150 J=J1,J2
      M=J-K
      Y(M)=Y(J)
  150 Q(M)=Q(J)
  160 L(31)=L(31)-K
      J1=L(49)
      DO 180 J=1,J1
      IF(EG(J).EQ.BO(2).OR.EG(J).EQ.BO(3)) GO TO 175
      IF(EG(J).NE.BO(7).AND.EG(J).NE.BO(8)) GO TO 180
      IF(LG3(J).GT.I) LG3(J)=LG3(J)-1
      GO TO 180
  175 IF(LG1(J).LE.(L(I+50)+K)) GO TO 180
      LG1(J)=LG1(J)-K
      LG2(J)=LG2(J)-K
  180 CONTINUE
C     TO 220--, STORE THE PRESENT VALUES OF THE Y AND Q ARRAYS AND OF
C     THE CURRENTS OF THE DISTRIBUTION TRANSFORMES TO THE MAIN BUS.
  200 L(36)=1
```

```
      NN=L(31)
      DO 210 N=1,NN
      YY(N)=Y(N)
  210 QQ(N)=Q(N)
      IF(L(4).LE.0) RETURN
      J1=L(1)+L(2)+L(3)+1
      J2=J1+L(4)-1
      DO 220 N=J1,J2
      BB(1,N)=B(1,N)
      BB(2,N)=B(2,N)
  220 BB(3,N)=B(3,N)
      RETURN
      END
```

```
      SUBROUTINE DISCON
C     DISCONNECT GENERATORS FROM THE BUSES OF THE MG SETS WHEN THE RE-
C     SPECTIVE  PHASE  CURRENTS ARE ZERO.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      DIMENSION YY(316),QQ(316)
      N1=L(1)+1
      N2=N1+L(2)-1
      I=N1
    1 IF(B(92,I).LE.0.0) GO TO 4
      B(92,I)=0.0
      K=I
C     DISCONNECT PHASE A.
    2 B(95,K)=10.0
    3 Y(J)=0.0
      Q(J)=0.0
C     DETERMINE IF ALL PHASES ARE DISCONNECTED.
      IF(B(95,K).LE.0.0.OR.B(96,K).LE.0.0.OR.B(97,K).LE.0.0) GO TO 22
      A(72,K)=100.0
      GO TO 60
    4 IF(B(93,I).LE.0.0) GO TO 6
      B(93,I)=0.0
      K=I
C     DISCONNECT PHASE B.
    5 B(96,K)=10.0
      GO TO 3
    6 IF(B(94,I).LE.0.0) GO TO 10
      B(94,I)=0.0
      K=I
C     DISCONNECT PHASE C.
    7 B(97,K)=10.0
      GO TO 3
   10 IF(I.GE.N2) GO TO 11
      I=I+1
      GO TO 1
C     TO 20--, DETERMINE GENERATOR TO BE DISCONNECTED.
   11 DO 13 I=N1,N2
      IF(A(69,I).GE.0.0) GO TO 13
      IF(X.LT.A(72,I)) GO TO 13
      K=I
      GO TO 20
   13 CONTINUE
      GO TO 60
   20 B(98,K)=K
   22 IF(B(95,K).GT.0.0) GO TO 35
C     TO 25--, DETERMINE IF PHASE A SHOULD BE DISCONNECTED.
      J=L(K+50)+8
   25 IF(Y(J)*YY(J)) 26,2,35
   26 B(92,K)=10.0
C     TO ABOVE 35--, BACKSTEP TO INTEGRATE TO ZERO CURRENT.
   27 X=X-D(31)
      D(31)=D(31)*YY(J)/(YY(J)-Y(J))
      NT=L(31)
      DO 30 I=1,NT
      Y(I)=YY(I)
```

```
   30 Q(I)=QQ(I)
      L(36)=2
      RETURN
   35 IF(B(96,K).GT.0.0) GO TO 40
C     TO 36--, DETERMINE IF PHASE B SHOULD BE DISCONNECTED.
      J=L(K+50)+9
   36 IF(Y(J)*YY(J)) 38,5,40
   38 B(93,K)=10.0
      GO TO 27
   40 IF(B(97,K).GT.0.0) GO TO 60
C     TO 48--, DETERMINE IF PHASE C SHOULD BE DISCONNECTED.
      J=L(K+50)+10
   48 IF(Y(J)*YY(J)) 50,7,60
   50 B(94,K)=10.0
      GO TO 27
C     STORE THE PRESENT VALUES OF THE Y AND Q ARRAYS.
   60 NT=L(31)
      DO 61 I=1,NT
      YY(I)=Y(I)
   61 QQ(I)=Q(I)
      L(36)=1
      RETURN
      END
```

```
      SUBROUTINE VMAX
C     COMPUTE THE PERCENT ERRORS OF THE PEAKS AND FREQUENCIES OF THE
C     LINE-TO-LINE VOLTAGES OF THE MAIN BUS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      DIMENSION V(21)
C     TO ABOVE 16--, SET CONTROLS FOR SPECIAL COMPUTATIONS DURING BUS
C     FAULTS.
      IF (X - C(9))  16,1,1
    1 IF (X - C(9) - D(31)) 2,2,8
    2 IF (L(7)) 16,16,3
    3 IF (L(7) - 3)  4,5,7
    4 IF (L(7) - 2)  16,7,7
    5 V(21) = 10.0
      V(20) = 10.0
    7 V(19) = 10.0
      GO TO 16
    8 IF (X - C(10)) 16,9,9
    9 IF (X - C(10) - D(31)) 10,10,16
   10 IF (L(7)) 16,16,11
   11 IF (L(7) - 3) 12,13,15
   12 IF (L(7) - 2) 16,15,15
   13 L(46) = 0
      GO TO 16
   15 V(13) = 0.0
      V(16) = 0.0
      V(19) = 0.0
      V(6) = 0.0
   16 IF (L(46))  17,17,19
C     TO 18--, SET THE ARRAY V TO ZERO.
   17 L(46) = 10
      DO 18 I=1,21
   18 V(I) = 0.0
   19 IF (D(31) - 0.1*C(1))  37,20,20
C     TO 21--, TRANSFER POINTS.
   20 V(1) = V(2)
      V(2) = V(3)
      V(4) = V(5)
      V(5) = V(6)
      V(7) = V(8)
      V(8) = V(9)
      V(10) = V(11)
      V(11) = V(12)
      V(3) = X
      V(6) = D(38)
      V(9) = D(39)
   21 V(12) = D(40)
      DO 35 I=1,3
      IF (V(I+18))  23,23,22
C     TO ABOVE 23--, SPECIAL COMPUTATIONS DURING BUS FAULTS.
   22 J = 2*I + 5
      D(J) = -100.0
      D(J+1) = -100.0
      D(I+12) = -100.0
      GO TO 35
```

```
   23 J = 3*I + 3
      J1=J-1
C     TO 29--, COMPUTATION OF PERCENT FREQUENCY ERRORS.
      IF (V(J))  25,24,25
   24 XE = V(3)
      GO TO 27
   25 IF(V(J)*V(J1)) 26,30,30
   26 XE = V(2) - V(J1)*(V(3) - V(2))/(V(J) - V(J1))
   27 J2 = I + 12
      IF (V(J2))  29,29,28
   28 D(J2) = 0.5/(XE - V(J2))
      D(2) = D(J2)/0.6 - 100.0
      D(J2) = D(2)
   29 V(J2) = XE
C     TO 35--, COMPUTATION OF PERCENT ERRORS OF PEAKS.
   30 J2 = I + 15
      V(J2) = V(J2) + 1.0
      IF (V(J2)- 3.0)  35,31,31
   31 J2 = J - 2
      IF ((V(J1) - V(J2))*(V(J1)-V(J))) 35,32,32
   32 W1 = V(J2)*(V(3) - V(2))
      W2 = V(J1)*(V(1) - V(3))
      W3 = V(J)*(V(2) - V(1))
      TE1 = W1*(V(3)+V(2))
      TE2 = W2*(V(1)+V(3))
      TE3 = W3*(V(2)+V(1))
      TE4 = W1+W2+W3
      XE = 0.5*(TE1+TE2+TE3)/TE4
      YE = V(J2)*(XE - V(2))*(XE - V(3))/(V(1) - V(2))/(V(1) - V(3)) +
     1 V(J1)*(XE - V(1))*(XE - V(3))/(V(2)- V(1))/(V(2)-V(3)) + V(J)*
     2 (XE - V(1))*(XE - V(2))/(V(3) - V(1))/(V(3)-V(2))
      IF(YE-V(J)) 33,34,34
   33 J = 2*I+6
      D(1) =-100.0*(YE/C(2) + 1.0)
      D(J) = D(1)
      GO TO 35
   34 J = 2*I + 5
      D(1) = 100.0*(YE/C(2) - 1.0)
      D(J) = D(1)
   35 CONTINUE
      IF (V(21)) 37,37,36
C     SPECIAL COMPUTATION DURING THREE PHASE BUS FAULT.
   36 D(1) = -100.0
      D(2) = -100.0
   37 RETURN
      END
```

```
      SUBROUTINE VMAXGB
C     COMPUTE THE PERCENT ERRORS OF THE PEAKS AND FREQUENCIES OF THE
C     LINE-TO-LINE VOLTAGES OF THE BUSES OF THE MG SETS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      L2=L(2)
      DO 100 K=1,L2
      N=K+L(1)
      IF(A(69,N).LT.0.0) GO TO 100
      IF(X.LT.A(75,N)) GO TO 16
C     TO ABOVE 16--, SET CONTROLS FOR SPECIAL COMPUTATIONS DURING BUS
C     FAULTS.
      M=IFIX(A(77,N)+0.00000001)
      IF(X.GT.(A(75,N)+D(31))) GO TO 8
      IF(M.LE.0) GO TO 16
      IF(M-3) 4,5,7
    4 IF(M-2) 16,7,7
    5 VV(21,K)=10.0
      VV(20,K)=10.0
    7 VV(19,K)=10.0
      GO TO 16
    8 IF(X.GT.(A(76,N)+D(31))) GO TO 16
      IF(M.LE.0) GO TO 16
      IF(M-3) 12,13,15
   12 IF(M-2) 16,15,15
   13 B(99,N)=0.0
      GO TO 16
   15 VV(13,K)=0.0
      VV(16,K)=0.0
      VV(19,K)=0.0
      VV(6,K)=0.0
   16 IF(B(99,N).GT.0.0) GO TO 19
C     TO 18--, SET THE ARRAY VV TO ZERO.
      DO 18 M=1,21
   18 VV(M,K)=0.0
      B(99,N)=10.0
   19 IF(D(31).LT.(0.1*C(1))) GO TO 100
C     TO 21--, TRANSFER POINTS.
      DO 20 M=1,11
      IF(M.EQ.3.OR.M.EQ.6.OR.M.EQ.9) GO TO 20
      VV(M,K)=VV(M+1,K)
   20 CONTINUE
      VV(3,K)=X
      VV(6,K)=B(77,N)
      VV(9,K)=B(78,N)
   21 VV(12,K)=B(79,N)
      DO 35 I=1,3
      IF(VV(I+18,K).LE.0.0) GO TO 23
C     TO ABOVE 23--, SPECIAL COMPUTATIONS DURING BUS FAULTS.
      J=2*I+63
      B(J,N)=-100.0
      B(J+1,N)=-100.0
      B(I+70,N)=-100.0
      GO TO 35
   23 J=3*I+3
```

```
      J1=J-1
C     TO 29--, COMPUTATION OF PERCENT FREQUENCY ERRORS.
      IF(VV(J,K).NE.0.0) GO TO 25
      XE=VV(3,K)
      GO TO 27
   25 IF((VV(J,K)*VV(J1,K)).GE.0.0) GO TO 30
      XE=VV(2,K)-VV(J1,K)*(VV(3,K)-VV(2,K))/(VV(J,K)-VV(J1,K))
   27 J2=I+12
      IF(VV(J2,K).LE.0.0) GO TO 29
      B(64,N)=-100.0+0.5/(0.6*(XE-VV(J2,K)))
      B(I+70,N)=B(64,N)
   29 VV(J2,K)=XE
C     TO 35--, COMPUTATION OF PERCENT ERRORS OF PEAKS.
   30 J2=I+15
      VV(J2,K)=VV(J2,K)+1.0
      IF(VV(J2,K).LT.3.0) GO TO 35
      J2=J-2
      IF(((VV(J1,K)-VV(J2,K))*(VV(J1,K)-VV(J,K))).LT.0.0) GO TO 35
      W1=VV(J2,K)*(VV(3,K)-VV(2,K))
      W2=VV(J1,K)*(VV(1,K)-VV(3,K))
      W3=VV(J,K)*(VV(2,K)-VV(1,K))
      TE1=W1*(VV(3,K)+VV(2,K))
      TE2=W2*(VV(1,K)+VV(3,K))
      TE3=W3*(VV(2,K)+VV(1,K))
      TE4=W1+W2+W3
      XE=0.5*(TE1+TE2+TE3)/TE4
      YE=VV(J2,K)*(XE-VV(2,K))*(XE-VV(3,K))/(VV(1,K)-VV(2,K))/(VV(1,K)-
     1VV(3,K))+VV(J1,K)*(XE-VV(1,K))*(XE-VV(3,K))/(VV(2,K)-VV(1,K))/(VV(
     22,K)-VV(3,K))+VV(J,K)*(XE-VV(1,K))*(XE-VV(2,K))/(VV(3,K)-VV(1,K))/
     3(VV(3,K)-VV(2,K))
      IF(YE.GE.VV(J,K)) GO TO 33
      J=2*I+64
      B(63,N)=-100.0*(YE/A(68,N)+1.0)
      GO TO 34
   33 J=2*I+63
      B(63,N)=100.0*(YE/A(68,N)-1.0)
   34 B(J,N)=B(63,N)
   35 CONTINUE
      IF(VV(21,K).LE.0.0) GO TO 100
C     SPECIAL COMPUTATION DURING THREE PHASE BUS FAULTS.
      B(63,N)=-100.0
      B(64,N)=-100.0
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TRAN
C     COMPUTE THE PHASE AND LINE-TO-LINE VOLTAGES AT THE SECONDARIES OF
C     DISTRIBUTION TRANSFORMERS, AND THE AVERAGE THREE-PHASE POWERS AND
C     THE PEAK REACTIVE POWERS PER PHASE OF THEIR LOADS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      N1 = L(1) + L(2) + L(3) + 1
      N2 = N1 + L(4) - 1
      DO 10 I = N1,N2
      L8 = IFIX(A(10,I) + 0.00000001)
      J = L(I+50)
      J1 = J+1
      J2 = J+2
      IF ( X.LT.A(8,I).OR.X.GT.A(9,I)) GO TO 1
      IF (L8 .LE. 3 ) GO TO 1
      B(4,I) = 0.5*(B(34,I)*(F(J)+F(J1))+B(31,I)*(Y(J)+Y(J1)))
      B(5,I)=B(4,I)
      B(6,I)=B(34,I)*F(J2)+B(31,I)*Y(J2)
      GO TO 2
    1 B(4,I)=B(34,I)*F(J)+B(31,I)*Y(J)
      B(5,I) = B(35,I)*F(J1)+B(32,I)*Y(J1)
      B(6,I) = B(36,I)*F(J2)+B(33,I)*Y(J2)
    2 B(7,I) = B(4,I)-B(5,I)
      B(8,I) = B(5,I) - B(6,I)
      B(9,I) = B(6,I) - B(4,I)
      B(10,I) = 0.001*( Y(J)*B(4,I)+Y(J1)*B(5,I)+Y(J2)*B(6,I))
      B(11,I) = 1.9245E-4*( Y(J)*B(8,I)+Y(J1)*B(9,I)+Y(J2)*B(7,I))
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE VMAXTR
C     COMPUTE THE PERCENT ERRORS OF THE PEAKS AND FREQUENCIES OF THE
C     LINE-TO-LINE VOLTAGES AT THE SECONDARIES OF DISTRIBUTION TRANS-
C     FORMERS
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      N1 = L(1) + L(2) + L(3) + 1
      N2 = N1 + L(4) - 1
      DO 200 I = N1, N2
      IF ( ( X - A(8,I)).LT. 0.0 ) GO TO 80
C     TO ABOVE 80--, SET CONTROLS FOR SPECIAL COMPUTATIONS DURING FAULTS
C     AT SECONDARIES.
      L8 = IFIX ( A(10,I) + 0.00000001 )
      IF ( ( X-A(8,I) - D(31)) .GT. 0.0 ) GO TO 40
      IF ( L8 .LE. 0 ) GO TO 80
      IF ( L8 - 3 ) 10, 20, 30
   10 IF ( L8 .GE. 2 ) GO TO 30
      GO TO 80
   20 G(21,I) = 10.0
      G(20,I) = 10.0
   30 G(19,I) = 10.0
      GO TO 80
   40 IF ( ( X-A(9,I)) .LT. 0.0 ) GO TO 80
      IF ( (X- A(9,I) - D(31)) .GT. 0.0 ) GO TO 80
      IF ( L8 .LE. 0 ) GO TO 80
      IF ( L8 - 3 ) 50, 60, 70
   50 IF ( L8 .GE. 2 ) GO TO 70
   60 A(20,I) = 0.0
      GO TO 80
   70 G(13,I) = 0.0
      G(16,I) = 0.0
      G(19,I) = 0.0
      G(6,I) = 0.0
   80 IF ( A(20,I) .GT. 0.0 ) GO TO 100
C     TO 90--, SET THE ARRAY G TO ZERO.
      A(20,I) = 10.0
      DO 90 J = 1,21
      G(J,I) = 0.0
   90 CONTINUE
  100 IF ( (D(31) - 0.1*C(1)) .LT. 0.0 ) GO TO 200
C     TO 120--, TRANSFER POINTS.
      DO 110 J = 1,12,3
      J1 = J+1
      G(J,I) = G(J1,I)
      G(J1,I) = G(J1+1,I)
  110 CONTINUE
      G(3,I) = X
      DO 120 J = 2,4
      G(3*J,I) = B(J+5,I)
  120 CONTINUE
      DO 190 J = 1,3
      IF ( G(J+18,I) .LE. 0.0 ) GO TO 130
C     TO ABOVE 130--, SPECIAL COMPUTATIONS DURING FAULTS AT SECONDARIES.
      K = 2*J + 12
      B(K,I) = -100.0
```

```
      B(K+1,I) = -100.0
      B(J+19,I) = -100.0
      GO TO 190
  130 K = 3*J + 3
      K1 = K - 1
C     TO 160--, COMPUTATION OF PERCENT FREQUENCY ERRORS.
      IF ( G(K,I) .NE. 0.0 ) GO TO 140
      XE = G(3,I)
      GO TO 150
  140 IF ( (G(K,I)*G(K1,I)) .GE. 0.0 ) GO TO 170
      XE = G(2,I) - G(K1,I)*(G(3,I) - G(2,I))/(G(K,I) - G(K1,I))
  150 K2 = J + 12
      IF ( G(K2,I) .LE. 0.0 ) GO TO 160
      B(J+19,I) = 0.5/(XE - G(K2,I))
      B(13,I) = B(J+19,I)/0.6-100.0
      B(J+19,I) = B(13,I)
  160 G(K2,I) = XE
C     TO 190--, COMPUTATION OF PERCENT ERRORS OF PEAKS.
  170 K2 = J + 15
      G(K2,I) = G(K2,I) + 1.0
      IF (( G(K2,I) - 3.0) .LT. 0.0 ) GO TO 190
      K2 = K - 2
      IF ( ((G(K1,I) - G(K2,I))*(G(K1,I) - G(K,I))) .LT. 0.0 ) GO TO 190
      G1 = G(K2,I) *(G(3,I) - G(2,I))
      G2 = G(K1,I)*(G(1,I) - G(3,I))
      G3 = G(K,I)*(G(2,I) - G(1,I))
      TE1 = G1*(G(3,I) + G(2,I))
      TE2 = G2*(G(1,I) + G(3,I))
      TE3 = G3*(G(2,I) + G(1,I))
      TE4 = G1 + G2 + G3
      XE = 0.5*(TE1 + TE2 + TE3)/TE4
      YE = G(K2,I)*(XE - G(2,I))*(XE - G(3,I))/(G(1,I) - G(2,I))/
     1 (G(1,I) - G(3,I)) + G(K1,I)*(XE - G(1,I))*(XE - G(3,I))/
     2 (G(2,I) - G(1,I))/(G(2,I) - G(3,I)) + G(K,I)*(XE - G(1,I))
     3*(XE - G(2,I))/(G(3,I) - G(1,I))/(G(3,I) - G(2,I))
      IF (YE.GE. G(K,I)) GO TO 180
      K = 2*J + 13
      B(12,I) = -100.0*(YE/A(12,I) + 1.0)
      B(K,I) = B(12,I)
      GO TO 190
  180 K = 2*J + 12
      B(12,I) = 100.0*(YE/A(12,I) - 1.0)
      B(K,I) = B(12,I)
  190 CONTINUE
       IF ( G(21,I) .LE. 0.0 ) GO TO 200
C     SPECIAL COMPUTATION DURING THREE PHASE FAULTS AT SECONDARIES.
      B(12,I) = -100.0
      B(13,I) = -100.0
  200 CONTINUE
      RETURN
      END
```

```
SUBROUTINE DUPLEX                                                       17 0000
RETURN
END
```

```
SUBROUTINE VMAXDR                                                      18 0000
RETURN
END
```

```
      SUBROUTINE YPRIM2
C     THIS IS A MAIN SUBROUTINE IN THE COMPUTATION OF THE DERIVATIVES OF
C     THE OEPENOENT VARIABLES OF SUB2.
C     IN THIS COMPUTATION, THE VARIOUS COMPONENTS OF THE PLANT ARE TRE-
C     ATEO IN THE FOLLOWING ORDER--ROTATING MACHINES ON MAIN BUS, OIS-
C     TRIBUTION TRANSFORMERS, COMMERCIAL POWER SYSTEM, OUPLEX REACTOR
C     AND HV POWER SUPPLIES, REGULATORS OF GENERATING UNITS, ALTERNATORS
C     OF MG SETS AND THEIR REGULATORS, ANO SHAFTS OF MG SETS ANO INOUCT-
C     ION MOTORS.
C     OURING THIS COMPUTATION, VARIOUS OTHER VARIABLES ARE COMPUTEO,
C     SUCH AS BUS VOLTAGES, POWERS, TORQUES, ETC.
      COMMON A,B,BO,C,CD,O,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAO
      OIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),O(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAO(39)
      IF(L(33)) 53,1,53
    1 NS=L(1)+L(2)+L(3)
      IF (L(2)+L(3)) 105,105,100
C     TO 77--, COMPUTE THE OERIVATIVES OF THE WINOING CURRENTS OF THE
C     ROTATING MACHINES CONNECTEO TO THE MAIN BUS, ANO THE DERIVATIVES
C     OF THE OEPENDENT VARIABLES OF DISTRIBUTION TRANSFORMERS, THE COM-
C     MERCIAL POWER SYSTEM AND THE OUPLEX REACTOR ANO HV POWER SUPPLIES.
C     TO 104--, COMPUTE THE ELECTRICAL SPEEOS OF MOTORS, THE RERCENT
C     SPEEO ERRORS OF SYNCHRONOUS MOTORS ANO THE PERCENT SLIPS OF
C     INDUCTION MOTORS.
  100 OO 104 I=1,NS
      LI=L(I+99)
      GO TO (104,101,102),LI
  101 J=L(I+50)+7
      B(5,I) = A(15,I)*Y(J)
      B(4,I)=100.0*(B(5,I)/377.0-1.0)
      GO TO 104
  102 J=L(I+50)+6
      B(5,I)=A(7,I)*Y(J)
      B(4,I) = 100.0*(1.0-B(5,I)/377.0)
  104 CONTINUE
  105 IF(NS.LE.0) GO TO 107
C     TO 106--, SET UP THE INDUCTANCE ANO ((IMPEOANCE)) MATRICES OF RO-
C     TATING MACHINES.
      CALL LMAT
      CALL IMAT
   12 IF((L(1)+L(2)).LE.0) GO TO 107
      CALL SAT
  106 CALL SATEF
  107 CALL RLMB
C     TO 111--, COMPUTE THE CURRENTS OF THE RL LOAD ANO OF THE TOTAL
C     LOAO OF THE MAIN BUS.
      DO 108 I=22,24
      O(I+6)=0.0
  108 D(I)=0.0
      IF(NS.LE.0) GO TO 109
      OO 18 I=1,NS
      J=L(I+50)
   16 O(22)=O(22)+Y(J)
      O(23)=O(23)+Y(J+1)
      O(24)=O(24)+Y(J+2)
      IF(I-L(1)) 17,17,18
```

```
   17 D(28)=D(28)+Y(J)
      D(29)=D(29)+Y(J+1)
      D(30)=D(30)+Y(J+2)
   18 CONTINUE
  109 IF (L(5).LE.0) GO TO 19
      NU=NS+L(4)+1
      J=L(NU+50)
      D(22)=D(22)+Y(J)
      D(23)=D(23)+Y(J+1)
      D(24)=D(24)+Y(J+2)
      D(28)=D(28)+Y(J)
      D(29)=D(29)+Y(J+1)
      D(30)=D(30)+Y(J+2)
   19 IF (L(6).LE.0) GO TO 110
      J=L(31)-5
      D(22)=D(22)+Y(J)
      D(23)=D(23)+Y(J+1)
      D(24)=D(24)+Y(J+2)
  110 IF(L(4).LE.0) GO TO 20
      N1=NS+1
      N2=N1+L(4)-1
      DO 111 I=N1,N2
      J=L(I+50)
      B(1,I)=(Y(J+2)-Y(J))/A(3,I)
      B(2,I)=(Y(J)-Y(J+1))/A(3,I)
      B(3,I)=(Y(J+1)-Y(J+2))/A(3,I)
      D(22)=D(22)+B(1,I)
      D(23)=D(23)+B(2,I)
  111 D(24)=D(24)+B(3,I)
   20 IF(NS.LE.0) GO TO 112
      CALL XLMAT
      CALL TRIAS
C     TO ABOVE 76--, SET UP THE MATRIX CD CONTAINING THE COEFFICIENTS OF
C     THE THREE EQUATIONS RELATING THE CURRENT DERIVATIVES OF THE RL
C     LOAD OF THE MAIN BUS.
  112 DO 200 I=1,3
      DO 200 J=1,4
  200 CD(I,J) = 0.0
      IF(NS.GT.0) CALL CDMACH
      IF(L(4).GT.0) CALL CDTRAN
      IF(L(5).GT.0) CALL CDCOMP
      IF (L(6).GT.0) CALL CDDR
      IF(X.LT.C(9).OR.X.GT.C(10)) GO TO 306
      IF (L(8) - 3)   306,306,304
C     TO 305--, ADJUST MATRIX CD DURING LINE-TO-LINE FAULT ON MAIN BUS.
  304 CD(2,1) = CD(2,1) + 1.0 + CD(1,1)
      CD(2,2) = CD(2,2) + 1.0 + CD(1,2)
      CD(2,3) = CD(2,3) + CD(1,3)
      CD(2,4) = CD(2,4) + CD(1,4)
      CD(3,3) = CD(3,3) + 1.0
      CD(1,1) = D(19)
      CD(1,2) = -D(20)
      CD(1,3) = 0.0
  305 CD(1,4) = D(17)*D(23) - D(16)*D(22)
      GO TO 76
  306 CD(1,1) = CD(1,1) + 1.0
      CD(2,2) = CD(2,2) + 1.0
      CD(3,3) = CD(3,3) + 1.0
   76 CALL MBSOLV
```

```
C     TO 77--, EVALUATE THE DERIVATIVES.
      IF(NS.GT.0) CALL FMACH
      IF(L(4).GT.0) CALL FTRAN
      IF (L(5).GT.0) CALL FCOMP
   77 IF (L(6).GT.0) CALL FDR
C     TO 78--, COMPUTE THE PHASE AND LINE-TO-LINE VOLTAGES OF THE MAIN
C     BUS.
      D(35)=D(16)*D(22)+D(19)*D(25)
      D(36)=D(17)*D(23)+D(20)*D(26)
      D(37)=D(18)*D(24)+D(21)*D(27)
      D(38) = D(35) - D(36)
      D(39) = D(36) - D(37)
   78 D(40) = D(37) - D(35)
      D(3)=0.0
      D(4)=0.0
      IF(L(5).LE.0) GO TO 41
C     TO 79--, COMPUTE THE AVERAGE THREE-PHASE POWER AND THE PEAK REACT-
C     IVE POWER PER PHASE OF THE COMMERCIAL POWER SYSTEM, AND THEIR CON-
C     TRIBUTIONS TO THE LOAD OF THE MAIN BUS.
      J=L(NU+50)
      D(5)=0.001*(D(35)*Y(J)+D(36)*Y(J+1)+D(37)*Y(J+2))
      D(6)=1.9245E-4*(Y(J)*D(39)+Y(J+1)*D(40)+Y(J+2)*D(38))
      D(3)=D(3)+D(5)
   79 D(4)=D(4)+D(6)
   41 IF(L(1).GT.0) CALL FREG
      IF(L(2).GT.0) CALL YPRIMG
      IF(NS.GT.0) CALL FMECH
   53 L(33)=0
      RETURN
      END
```

```
      SUBROUTINE LMAT
C     SET UP THE INDUCTANCE MATRICES, WITHOUT FIELD SATURATION EFFECTS,
C     OF THE ROTATING MACHINES CONNECTED TO THE MAIN BUS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      CC=0.866025404
      NS=L(1)+L(2)+L(3)
      DO 10 I=1,NS
      LI=L(I+99)
      GO TO (1,1,2),LI
    1 J=L(I+50)+6
      GO TO 4
    2 J=L(I+50)+5
    4 XL(1,1,I)=A(1,I)
      XL(2,1,I)=-A(2,I)
      XL(3,1,I)=XL(2,1,I)
      XL(2,2,I)=XL(1,1,I)
      XL(3,2,I)=XL(2,1,I)
      XL(3,3,I)=XL(1,1,I)
      B(19,I)=COS(Y(J))
      B(20,I)=SIN(Y(J))
      C1=0.5*B(19,I)
      C2=CC*B(19,I)
      C3=0.5*B(20,I)
      C4=CC*B(20,I)
      B(21,I)=-C1-C4
      B(22,I)=-C3+C2
      B(23,I)=-C1+C4
      B(24,I)=-C3-C2
      XL(4,1,I)=-A(4,I)*B(19,I)
      XL(4,2,I)=-A(4,I)*B(23,I)
      XL(4,3,I)=-A(4,I)*B(21,I)
      GO TO (6,6,5),LI
    5 XL(4,4,I) = A(3,I)
      XL(5,1,I)=A(4,I)*B(20,I)
      XL(5,2,I)=A(4,I)*B(24,I)
      XL(5,3,I)=A(4,I)*B(22,I)
      GO TO 8
    6 XL(4,4,I) = A(7,I)
      XL(5,1,I)=-A(5,I)*B(19,I)
      XL(5,2,I)=-A(5,I)*B(23,I)
      XL(5,3,I)=-A(5,I)*B(21,I)
      XL(5,4,I)=A(8,I)
      XL(5,5,I)=A(9,I)
      XL(6,1,I)=A(6,I)*B(20,I)
      XL(6,2,I)=A(6,I)*B(24,I)
      XL(6,3,I)=A(6,I)*B(22,I)
      IF(A(3,I)) 8,8,7
C     TO ABOVE 8, SALIENCY EFFECTS FOR SYNCHRONOUS MACHINES.
    7 B(25,I)=2.0*B(19,I)*B(19,I)-1.0
      B(26,I)=2.0*B(19,I)*B(20,I)
      C1=0.5*B(25,I)
      C2=CC*B(25,I)
      C3=0.5*B(26,I)
      C4=CC*B(26,I)
```

```
      B(27,I)=-C1-C4
      B(28,I)=-C3+C2
      B(29,I)=-C1+C4
      B(30,I)=-C3-C2
      XL(1,1,I)=XL(1,1,I)+A(3,I)*B(25,I)
      XL(2,1,I)=XL(2,1,I)+A(3,I)*B(29,I)
      XL(3,1,I)=XL(3,1,I)+A(3,I)*B(27,I)
      XL(2,2,I)=XL(2,2,I)+A(3,I)*B(27,I)
      XL(3,2,I)=XL(3,2,I)+A(3,I)*B(25,I)
      XL(3,3,I)=XL(3,3,I)+A(3,I)*B(29,I)
    8 XL(1,2,I)=XL(2,1,I)
      XL(1,3,I)=XL(3,1,I)
      XL(1,4,I)=XL(4,1,I)
      XL(1,5,I)=XL(5,1,I)
      XL(2,3,I)=XL(3,2,I)
      XL(2,4,I)=XL(4,2,I)
      XL(2,5,I)=XL(5,2,I)
      XL(3,4,I)=XL(4,3,I)
      XL(3,5,I)=XL(5,3,I)
      XL(4,5,I)=XL(5,4,I)
      GO TO (9,9,10),LI
    9 XL(1,6,I)=XL(6,1,I)
      XL(2,6,I)=XL(6,2,I)
      XL(3,6,I)=XL(6,3,I)
      XL(4,6,I)=XL(6,4,I)
      XL(5,6,I)=XL(6,5,I)
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE IMAT
C     SET UP THE ((IMPEDANCE)) MATRICES, WITHOUT FIELD SATURATION EF-
C     FECTS, OF THE ROTATING MACHINES CONNECTED TO THE MAIN BUS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      NS=L(1)+L(2)+L(3)
      DO 9 I=1,NS
      LI=L(I+99)
      GO TO (1,1,4),LI
    1 CONTINUE
      IF(A(3,I)) 3,3,2
C     TO ABOVE 3, SALIENCY EFFECTS FOR SYNCHRONOUS MACHINES.
    2 CC=-2.0*A(3,I)*B(5,I)
      Z(2,1,I)=CC*B(30,I)
      Z(3,1,I)=CC*B(28,I)
      Z(3,2,I)=CC*B(26,I)
      Z(1,1,I)=A(11,I)+Z(3,2,I)
      Z(2,2,I)=A(11,I)+Z(3,1,I)
      Z(3,3,I)=A(11,I)+Z(2,1,I)
      GO TO 4
    3 Z(1,1,I)=A(11,I)
      Z(2,1,I)=0.0
      Z(3,1,I)=0.0
      Z(2,2,I)=A(11,I)
      Z(3,2,I)=0.0
      Z(3,3,I)=A(11,I)
    4 CC=A(4,I)*B(5,I)
      Z(4,1,I)=CC*B(20,I)
      Z(4,2,I)=CC*B(24,I)
      Z(4,3,I)=CC*B(22,I)
      GO TO (5,5,6),LI
    5 CC=A(5,I)*B(5,I)
      Z(5,1,I)=CC*B(20,I)
      Z(5,2,I)=CC*B(24,I)
      Z(5,3,I)=CC*B(22,I)
      CC=A(6,I)*B(5,I)
      Z(6,1,I)=CC*B(19,I)
      Z(6,2,I)=CC*B(23,I)
      Z(6,3,I)=CC*B(21,I)
      GO TO 7
    6 CC=A(4,I)*B(5,I)
      Z(5,1,I)=CC*B(19,I)
      Z(5,2,I)=CC*B(23,I)
      Z(5,3,I)=CC*B(21,I)
    7 Z(1,4,I)=Z(4,1,I)
      Z(1,5,I)=Z(5,1,I)
      Z(2,4,I)=Z(4,2,I)
      Z(2,5,I)=Z(5,2,I)
      Z(3,4,I)=Z(4,3,I)
      Z(3,5,I)=Z(5,3,I)
      GO TO (8,8,9),LI
    8 Z(1,2,I) = Z(2,1,I)
      Z(1,3,I) = Z(3,1,I)
      Z(2,3,I) = Z(3,2,I)
      Z(1,6,I)=Z(6,1,I)
```

```
      Z(2,6,I)=Z(6,2,I)
      Z(3,6,I)=Z(6,3,I)
    9 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SAT
C     DETERMINE IF THE FIELDS OF THE SYNCHRONOUS MACHINES CONNECTED TO
C     THE MAIN BUS ARE SATURATED, AND COMPUTE THE FIELD FLUX LINKAGES,
C     THE EQUIVALENT FIELD SATURATION CURRENTS, AND THE DERIVATIVES OF
C     THE LATTER WITH RESPECT TO THE FORMER.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      NT=L(1)+L(2)
      DO 7 I=1,NT
      J=L(I+50)-1
    3 B(6,I)=0.0
      DO 4 K=1,5
      M=J+K
    4 B(6,I)=B(6,I)+XL(4,K,I)*Y(M)
      IF(B(6,I)-A(16,I)) 5,5,6
    5 B(7,I)=0.0
      B(8,I)=0.0
      L(I+10)=1
      GO TO 7
    6 C1=A(16,I)-0.5/(A(17,I)*A(7,I))
      C2=C1*C1+B(6,I)/(A(17,I)*A(7,I))-A(16,I)*A(16,I)
      C2=SQRT(C2)
      B(6,I)=C1+C2
      B(7,I)=A(17,I)*(B(6,I)-A(16,I))*(B(6,I)-A(16,I))
      B(8,I)=2.0*A(17,I)*(B(6,I)-A(16,I))
      L(I+10)=2
    7 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SATEF
C     ADD FIELD SATURATION EFFECTS TO THE INDUCTANCE AND ((IMPEDANCE))
C     MATRICES OF THE SYNCHRONOUS MACHINES CONNECTED TO THE MAIN BUS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      NT=L(1)+L(2)
      DO 2 I=1,NT
      L20=L(I+10)
      GO TO (2,1),L20
    1 C1=A(4,I)*B(8,I)/(1.0+A(7,I)*B(8,I))
      C2=A(4,I)*C1
      C3=C1*B(19,I)
      C4=C2*B(19,I)
      XL(1,1,I)=XL(1,1,I)-C4*B(19,I)
      XL(2,1,I)=XL(2,1,I)-C4*B(23,I)
      XL(3,1,I)=XL(3,1,I)-C4*B(21,I)
      XL(4,1,I)=XL(4,1,I)+C3*A(7,I)
      XL(5,1,I)=XL(5,1,I)+C3*A(8,I)
      C3=C1*B(23,I)
      C4=C2*B(23,I)
      XL(2,2,I)=XL(2,2,I)-C4*B(23,I)
      XL(3,2,I)=XL(3,2,I)-C4*B(21,I)
      XL(4,2,I)=XL(4,2,I)+C3*A(7,I)
      XL(5,2,I)=XL(5,2,I)+C3*A(8,I)
      XL(3,3,I)=XL(3,3,I)-C2*B(21,I)*B(21,I)
      C3=C1*B(21,I)
      XL(4,3,I)=XL(4,3,I)+C3*A(7,I)
      XL(5,3,I)=XL(5,3,I)+C3*A(8,I)
      C3=C1*A(7,I)/A(4,I)
      XL(4,4,I)=XL(4,4,I)-C3*A(7,I)
      XL(5,4,I)=XL(5,4,I)-C3*A(8,I)
      XL(5,5,I)=XL(5,5,I)-C1*A(8,I)*A(8,I)/A(4,I)
      C1=C1*B(5,I)
      C2=C2*B(5,I)
      C3=C1*B(20,I)
      C4=C2*B(20,I)
      Z(1,1,I)=Z(1,1,I)+C4*B(19,I)
      Z(2,1,I)=Z(2,1,I)+C4*B(23,I)
      Z(3,1,I)=Z(3,1,I)+C4*B(21,I)
      Z(4,1,I)=Z(4,1,I)-C3*A(7,I)
      Z(5,1,I)=Z(5,1,I)-C3*A(8,I)
      C3=C1*B(24,I)
      C4=C2*B(24,I)
      Z(1,2,I) = Z(1,2,I) + C4*B(19,I)
      Z(2,2,I)=Z(2,2,I)+C4*B(23,I)
      Z(3,2,I)=Z(3,2,I)+C4*B(21,I)
      Z(4,2,I)=Z(4,2,I)-C3*A(7,I)
      Z(5,2,I)=Z(5,2,I)-C3*A(8,I)
      C3 = C1*B(22,I)
      C4 = C2*B(22,I)
      Z(1,3,I) = Z(1,3,I) + C4*B(19,I)
      Z(2,3,I) = Z(2,3,I) + C4*B(23,I)
      Z(3,3,I) = Z(3,3,I) + C4*B(21,I)
      Z(4,3,I)=Z(4,3,I)-C3*A(7,I)
      Z(5,3,I)=Z(5,3,I)-C3*A(8,I)
```

```
      XL(1,2,I)=XL(2,1,I)
      XL(1,3,I)=XL(3,1,I)
      XL(1,4,I)=XL(4,1,I)
      XL(1,5,I)=XL(5,1,I)
      XL(2,3,I)=XL(3,2,I)
      XL(2,4,I)=XL(4,2,I)
      XL(2,5,I)=XL(5,2,I)
      XL(3,4,I)=XL(4,3,I)
      XL(3,5,I)=XL(5,3,I)
      XL(4,5,I)=XL(5,4,I)
      C1=A(4,I)*B(5,I)
      B(9,I)=C1*B(20,I)
      B(10,I)=C1*B(24,I)
      B(11,I)=C1*B(22,I)
    2 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE RLMB
C     COMPUTE THE INSTANTANEOUS VALUES OF THE PHASE RESISTANCES AND IN-
C     DUCTANCES OF THE RL LOAD OF THE MAIN BUS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      DO 1 I=3,8
      J=I+13
    1 D(J) = C(I)
      IF (X.LT.C(11)) GO TO 3
C     TO 2--, STEP CHANGE IN RL LOAD.
      C1=1.0+C(12)
      DO 2 I=16,21
    2 D(I) = C1*D(I)
    3 IF(X.LT.C(13)) GO TO 5
C     TO 4--, SINUSOIDAL VARIATION OF RL LOAD.
      C1=C(14)*(X-C(13))
      C2=1.0+C(15)*SIN(C1)
      C1=C(15)*C(14)*COS(C1)
      DO 4 I=16,18
      J=I+3
      D(I)=C2*D(I)+C1*D(J)
    4 D(J)=C2*D(J)
    5 IF(X.LT.C(9).OR.X.GT.C(10)) GO TO 9
C     TO ABOVE 9--, ADJUST VALUES DURING ONE, TWO, OR THREE PHASE FAULTS
C     ON MAIN BUS.
      L7=L(7)
      IF(L7.LE.0.OR.L7.GT.3) GO TO 9
      GO TO (8,7,6),L7
    6 D(18)=0.0
      D(21) = 0.0
    7 D(17)=0.0
      D(20)=0.0
    8 D(16)=0.0
      D(19)=0.0
    9 RETURN
      END
```

```
      SUBROUTINE XLMAT
C     SET UP THE MATRIX XL CONTAINING THE COEFFICIENTS OF THE EQUATIONS
C     RELATING THE WINDING CURRENT DERIVATIVES OF EACH ROTATING MACHINE,
C     CONNECTED TO THE MAIN BUS, TO THE CURRENT DERIVATIVES OF THE RL
C     LOAD OF THE MAIN BUS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      NS=L(1)+L(2)+L(3)
      C1=D(16)*D(22)
      C2=D(17)*D(23)
      C3=D(18)*D(24)
      DO 33 I=1,NS
      LI=L(I+99)
      J=L(I+50)-1
      IF(LI.GE.3) GO TO 110
C     TO 100--, CONTRIBUTIONS FROM THE GROUNDING REACTORS OF SYNCHRONOUS
C     MACHINES.
      C4=A(21,I)
      IF(C4.LE.0.0) GO TO 110
      DO 100 K=1,3
      DO 100 M=1,3
  100 XL(K,M,I)=XL(K,M,I)+C4
  110 DO 22 K=1,6
      DO 21 M=7,10
   21 XL(K,M,I)=0.0
   22 CONTINUE
      XL(1,7,I)=-C1+B(7,I)*B(9,I)
      XL(1,8,I)=-D(19)
      XL(2,7,I)=-C2+B(7,I)*B(10,I)
      XL(2,9,I)=-D(20)
      XL(3,7,I)=-C3+B(7,I)*B(11,I)
      XL(3,10,I)=-D(21)
      GO TO (24,23,25),LI
C     TO 210--, CONTRIBUTION FROM THE FIELD VOLTAGE OF SYNCHRONOUS MO-
C     TORS. (EXCITER MODEL.)
   23 IF((60.0-B(5,I)/6.283).GE.A(24,I)) GO TO 200
      IF(Y(J+4).LT.0.0) GO TO 200
      C4=0.005*(D(7)+D(8))
      IF(A(23,I).LT.0.0) C4=0.005*(D(9)+D(10))
      B(12,I)=A(22,I)*C(2)*(1.0+C4)
      GO TO 210
  200 B(12,I)=-A(25,I)*Y(J+4)
  210 XL(4,7,I)=B(12,I)
      JJ=6
      GO TO 15
   24 JJ=6
C     TO ABOVE 25--, CONTRIBUTIONS FROM THE FIELD VOLTAGE OF SYNCHRONOUS
C     ALTERNATORS. (EXCITER MODEL.)
      IF(ABS(Y(J+8)).GT.A(33,I)) Y(J+8)=SIGN(A(33,I),Y(J+8))
      IF (ABS(B(14,I)).LT.A(32,I)) GO TO 30
      XL(4,7,I)=SIGN(A(32,I),B(14,I))
      GO TO 15
   30 C4=2.0*(A(12,I)+A(31,I))/(3.0*A(4,I)*B(5,I))
      C5=C4*(A(1,I)+A(2,I)+1.5*A(3,I))*B(5,I)
      XL(4,7,I)=C5*(Y(J+1)*B(19,I)+Y(J+2)*B(23,I)+Y(J+3)*B(21,I))-C4*(
```

```
     1D(16)*D(22)*B(20,I)+D(17)*D(23)*B(24,I)+D(18)*D(24)*B(22,I))+Y(J
     2+8)-A(31,I)*Y(J+4)
      XL(4,8,I)=-C4*D(19)*B(20,I)
      XL(4,9,I)=-C4*D(20)*B(24,I)
      XL(4,10,I)=-C4*D(21)*B(22,I)
      GO TO 15
   25 JJ=5
   15 DO 27 K=1,JJ
      DO 26 M=1,JJ
      N=J+M
   26 XL(K,7,I)=XL(K,7,I)-Z(K,M,I)*Y(N)
   27 CONTINUE
   33 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TRIAS
C     FOR EACH ROTATING MACHINE CONNECTED TO THE MAIN BUS, TRIANGULARIZE
C     THE CORRESPONDING PART OF THE MATRIX XL.
C     THE RUN IS ABORTED IF ANY SUCH PART OF XL IS SINGULAR, AND A COM-
C     MENT IS WRITTEN IN TAPE 6.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
  100 FORMAT(1H1,24HABNORMAL EXIT FROM TRIAS/28H THE XL MATRIX OF SET NU
     1MBER,I3,12H IS SINGULAR)
      NS=L(1)+L(2)+L(3)
      DO 23 I=1,NS
      LI=L(I+99)
      GO TO (1,1,2),LI
    1 J=7
      GO TO 3
    2 J=6
    3 J=J-1
      IF(ABS(XL(J,J,I))-1.0E-30) 4,4,12
    4 IF(J-1) 5,5,6
C     SINGULAR MATRIX. ABORT RUN.
    5 WRITE(6,100) I
      CALL EXIT
    6 J1=J
    7 J1=J1-1
      IF(ABS(XL(J1,J,I))-1.0E-30) 8,8,9
    8 IF(J1-1) 5,5,7
    9 DO 10 K=1,J
      W1=XL(J,K,I)
      XL(J,K,I)=XL(J1,K,I)
   10 XL(J1,K,I)=W1
      DO 11 K=7,10
      W1=XL(J,K,I)
      XL(J,K,I)=XL(J1,K,I)
   11 XL(J1,K,I)=W1
   12 JJ=J-1
      IF(JJ) 15,15,13
   13 DO 14 K=1,JJ
   14 XL(J,K,I)=XL(J,K,I)/XL(J,J,I)
   15 DO 16 K=7,10
   16 XL(J,K,I)=XL(J,K,I)/XL(J,J,I)
      IF(JJ) 23,23,17
   17 J1=J-1
   18 IF(XL(J1,J,I)) 19,22,19
   19 DO 20 K=1,JJ
   20 XL(J1,K,I)=XL(J1,K,I)-XL(J1,J,I)*XL(J,K,I)
      DO 21 K=7,10
   21 XL(J1,K,I)=XL(J1,K,I)-XL(J1,J,I)*XL(J,K,I)
   22 J1=J1-1
      IF(J1) 3,3,18
   23 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CDMACH
C     COMPUTE THE CONTRIBUTIONS TO THE MATRIX CD FROM EACH ROTATING MA-
C     CHINE CONNECTED TO THE MAIN BUS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      NS = L(1) + L(2) + L(3)
      DO 35 I=1,NS
      IF(I-L(43)) 33,24,33
   24 IF(L(40)) 25,25,27
   25 CD(1,1) = CD(1,1)-XL(1,8,I)
      CD(1,2) = CD(1,2)-XL(1,9,I)
      CD(1,3) = CD(1,3)-XL(1,10,I)
      CD(1,4) = CD(1,4)+XL(1,7,I)
      IF(L(41)) 26,26,31
   26 CD(2,1)=CD(2,1)-XL(2,8,I)+XL(2,1,I)*XL(1,8,I)
      CD(2,2)=CD(2,2)-XL(2,9,I)+XL(2,1,I)*XL(1,9,I)
      CD(2,3)=CD(2,3)-XL(2,10,I)+XL(2,1,I)*XL(1,10,I)
      CD(2,4)=CD(2,4)+XL(2,7,I)-XL(2,1,I)*XL(1,7,I)
      IF(L(42)) 34,34,35
   27 IF(L(41)) 28,28,30
C     FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE B WHEN PHASE A OF A
C     MACHINE IS DISCONNECTED FROM THE MAIN BUS.
   28 CD(2,1)=CD(2,1)-XL(2,8,I)
      CD(2,2)=CD(2,2)-XL(2,9,I)
      CD(2,3)=CD(2,3)-XL(2,10,I)
      CD(2,4)=CD(2,4)+XL(2,7,I)
      IF(L(42)) 29,29,35
C     FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE C WHEN ONLY PHASE A OF
C     A MACHINE IS DISCONNECTED FROM THE MAIN BUS.
   29 CD(3,1)=CD(3,1)-XL(3,8,I)+XL(3,2,I)*XL(2,8,I)
      CD(3,2)=CD(3,2)-XL(3,9,I)+XL(3,2,I)*XL(2,9,I)
      CD(3,3)=CD(3,3)-XL(3,10,I)+XL(3,2,I)*XL(2,10,I)
      CD(3,4)=CD(3,4)+XL(3,7,I)-XL(3,2,I)*XL(2,7,I)
      GO TO 35
C     FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE C WHEN PHASES A AND B
C     OF A MACHINE ARE DISCONNECTED FROM THE MAIN BUS.
   30 CD(3,1)=CD(3,1)-XL(3,8,I)
      CD(3,2)=CD(3,2)-XL(3,9,I)
      CD(3,3)=CD(3,3)-XL(3,10,I)
      CD(3,4)=CD(3,4)+XL(3,7,I)
      GO TO 35
   31 IF(L(42)) 32,32,35
C     FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE C WHEN ONLY PHASE B OF
C     A MACHINE IS DISCONNECTED FROM THE MAIN BUS.
   32 CD(3,1)=CD(3,1)-XL(3,8,I)+XL(3,1,I)*XL(1,8,I)
      CD(3,2)=CD(3,2)-XL(3,9,I)+XL(3,1,I)*XL(1,9,I)
      CD(3,3)=CD(3,3)-XL(3,10,I)+XL(3,1,I)*XL(1,10,I)
      CD(3,4)=CD(3,4)+XL(3,7,I)-XL(3,1,I)*XL(1,7,I)
      GO TO 35
   33 CD(1,1)=CD(1,1)-XL(1,8,I)
      CD(1,2)=CD(1,2)-XL(1,9,I)
      CD(1,3)=CD(1,3)-XL(1,10,I)
      CD(1,4)=CD(1,4)+XL(1,7,I)
      CD(2,1)=CD(2,1)-XL(2,8,I)+XL(2,1,I)*XL(1,8,I)
      CD(2,2)=CD(2,2)-XL(2,9,I)+XL(2,1,I)*XL(1,9,I)
```

```
      CD(2,3)=CD(2,3)-XL(2,10,I)+XL(2,1,I)*XL(1,10,I)
      CD(2,4)=CD(2,4)+XL(2,7,I)-XL(2,1,I)*XL(1,7,I)
   34 CD(3,1)=CD(3,1)-XL(3,8,I)+XL(3,2,I)*XL(2,8,I)+XL(1,8,I)*(XL(3,1,I)
     1 -XL(2,1,I)*XL(3,2,I))
      CD(3,2)=CD(3,2)-XL(3,9,I)+XL(3,2,I)*XL(2,9,I)+XL(1,9,I)*(XL(3,1,I)
     1 -XL(2,1,I)*XL(3,2,I))
      CD(3,3)=CD(3,3)-XL(3,10,I)+XL(3,2,I)*XL(2,10,I)+XL(1,10,I)*(XL(3,1
     1,I)-XL(2,1,I)*XL(3,2,I))
      CD(3,4)=CD(3,4)+XL(3,7,I)-XL(3,2,I)*XL(2,7,I)-XL(1,7,I)*(XL(3,1,I)
     1 -XL(2,1,I)*XL(3,2,I))
   35 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CDTRAN
C     FOR EACH DISTRIBUTION TRANSFORMER CONNECTED TO THE MAIN BUS,
C     COMPUTE B(39,I) TO B(50,I), WHICH ARE THE COEFFICIENTS OF THE
C     THREE EQUATIONS RELATING THE DERIVATIVES OF THE SECONDARY CURRENTS
C     TO THE CURRENT DERIVATIVES OF THE RL LOAD OF THE MAIN BUS, AND
C     COMPUTE THE CONTRIBUTIONS TO THE MATRIX CD.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      N1=L(1)+L(2)+L(3)+1
      N2=N1+L(4)-1
      DO 200 I=N1,N2
C     TO 20--, COMPUTE THE INSTANTANEOUS VALUES OF THE PHASE RESISTANCES
C     AND INDUCTANCES OF THE RL LOAD OF EACH TRANSFORMER.
      DO 10 J=31,33
      B(J,I)=A(4,I)
      B(J+3,I)=A(5,I)
   10 CONTINUE
      IF(X.LT.A(6,I)) GO TO 30
C     TO 20--, STEP CHANGE IN RL LOAD.
      C1=1.0+A(7,I)
      DO 20 J=31,36
      B(J,I)=C1*B(J,I)
   20 CONTINUE
C     TO 159--, COMPUTE B(39,I) TO B(50,I).
   30 DO 40 J=39,50
      B(J,I)=0.0
   40 CONTINUE
      J=L(I+50)
      IF(X.LT.A(8,I).OR.X.GT.A(9,I)) GO TO 60
      L8=IFIX(A(10,I)+0.000000001)
      IF(L8.GE.4) GO TO 110
      IF(L8.LE.0) GO TO 60
C     TO 59--, ADJUST THE PHASE RESISTANCES AND INDUCTANCES OF THE
C     TRANSFORMER RL LOAD DURING A ONE, TWO, OR THREE PHASE FAULT ON SE-
C     CONDARY.
      GO TO (50,49,48),L8
   48 B(33,I)=0.0
      B(36,I)=0.0
   49 B(32,I)=0.0
      B(35,I)=0.0
   50 B(31,I)=0.0
   59 B(34,I)=0.0
   60 IF(I.NE.L(43)) GO TO 70
      IF(L(40).GT.0) GO TO 80
      IF(L(41).GT.0) GO TO 90
      IF(L(42).GT.0) GO TO 100
C     TO 79--, GENERAL EXPRESSIONS.
   70 C1=1.0/(A(2,I)+B(34,I))
      C2=C1/A(3,I)
      B(39,I)=-C1*Y(J)*(A(1,I)+B(31,I))+C2*(D(16)*D(22)-D(17)*D(23))
      B(40,I)=C2*D(19)
      B(41,I)=-C2*D(20)
      C1=1.0/(A(2,I)+B(35,I))
      C2=C1/A(3,I)
      B(43,I)=-C1*Y(J+1)*(A(1,I)+B(32,I))+C2*(D(17)*D(23)-D(18)*D(24))
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      B(45,I)=C2*D(20)
      B(46,I)=-C2*D(21)
      C1=1.0/(A(2,I)+B(36,I))
      C2=C1/A(3,I)
      B(47,I)=-C1*Y(J+2)*(A(1,I)+B(33,I))+C2*(D(18)*D(24)-D(16)*D(22))
      B(48,I)=-C2*D(19)
   79 B(50,I)=C2*D(21)
      GO TO 160
C     TO 89--, PHASE A OF TRANSFORMER DISCONNECTED FROM THE MAIN BUS.
   80 C1=1.0/(2.0*A(2,I)+B(34,I)+B(36,I))
      C2=C1/A(3,I)
      B(39,I)=-C1*Y(J)*(2.0*A(1,I)+B(31,I)+B(33,I))-C2*(D(17)*D(23)-D(18
     1)*D(24))
      B(41,I)=-C2*D(20)
      B(42,I)=C2*D(21)
      C1=1.0/(A(2,I)+B(35,I))
      C2=C1/A(3,I)
      B(43,I)=-C1*Y(J+1)*(A(1,I)+B(32,I))+C2*(D(17)*D(23)-D(18)*D(24))
      B(45,I)=C2*D(20)
      B(46,I)=-C2*D(21)
      B(47,I)=B(39,I)
      B(49,I)=B(41,I)
   89 B(50,I)=B(42,I)
      GO TO 160
C     TO 99--, PHASE B OF TRANSFORMER DISCONNECTED FROM THE MAIN BUS.
   90 C1=1.0/(2.0*A(2,I)+B(34,I)+B(35,I))
      C2=C1/A(3,I)
      B(39,I)=-C1*Y(J)*(2.0*A(1,I)+B(31,I)+B(32,I))-C2*(D(18)*D(24)-D(16
     1)*D(22))
      B(40,I)=C2*D(19)
      B(42,I)=-C2*D(21)
      B(43,I)=B(39,I)
      B(44,I)=B(40,I)
      B(46,I)=B(42,I)
      C1=1.0/(A(2,I)+B(36,I))
      C2=C1/A(3,I)
      B(47,I)=-C1*Y(J+2)*(A(1,I)+B(33,I))+C2*(D(18)*D(24)-D(16)*D(22))
      B(48,I)=-C2*D(19)
   99 B(50,I)=C2*D(21)
      GO TO 160
C     TO 109--, PHASE C OF TRANSFORMER DISCONNECTED FROM THE MAIN BUS.
  100 C1=1.0/(A(2,I)+B(34,1))
      C2=C1/A(3,I)
      B(39,I)=-C1*Y(J)*(A(1,I)+B(31,I))+C2*(D(16)*D(22)-D(17)*D(23))
      B(40,I)=C2*D(19)
      B(41,I)=-C2*D(20)
      C1=1.0/(2.0*A(2,I)+B(35,I)+B(36,I))
      C2=C1/A(3,I)
      B(43,I)=-C1*Y(J+1)*(2.0*A(1,I)+B(32,I)+B(33,I))-C2*(D(16)*D(22)-D(
     117)*D(23))
      B(44,I)=-C2*D(19)
      B(45,I)=C2*D(20)
      B(47,I)=B(43,I)
      B(48,I)=B(44,I)
  109 B(49,I)=B(45,I)
      GO TO 160
  110 IF(I.NE.L(43)) GO TO 120
      IF(L(40).GT.0) GO TO 130
      IF(L(41).GT.0) GO TO 140
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      IF(L(42).GT.0) GO TO 150
C     TO 129--, LINE-TO-LINE FAULT ON SECONDARY.
  120 C8=0.5/(A(2,I)+B(34,I))
      C10=C8*(A(1,I)+B(31,I))
      C8=C8/A(3,I)
      C9=0.5/A(2,I)
      C1=C10*(Y(J)+Y(J+1))
      C2=C9*A(1,I)*(Y(J)-Y(J+1))
      C9=C9/A(3,I)
      C3=C8*(D(18)*D(24)-D(16)*D(22))
      C4=C9*(D(16)*D(22)+D(18)*D(24)-2.0*D(17)*D(23))
      C5=C8*D(21)
      C6=C8*D(19)
      C7=C9*D(19)
      C8=2.0*C9*D(20)
      C9=C9*D(21)
      B(39,I)=-C1-C2-C3+C4
      B(40,I)=C6+C7
      B(41,I)=-C8
      B(42,I)=-C5+C9
      B(43,I)=-C1+C2-C3-C4
      B(44,I)=C6-C7
      B(45,I)=C8
      B(46,I)=-C5-C9
      B(47,I)=2.0*(-C10*Y(J+2)+C3)
      B(48,I)=-2.0*C6
  129 B(50,I)=2.0*C5
      GO TO 160
C     TO 139--, LINE-TO-LINE FAULT ON SECONDARY AND PHASE A OF TRANS-
C     FORMER DISCONNECTED FROM THE MAIN BUS.
  130 C6=1.0/(A(2,I)+0.25*B(34,I))
      C1=(A(1,I)+B(31,I))*(2.0*Y(J)+Y(J+1))/(3.0*(A(2,I)+B(34,I)))
      C2=C6*(A(1,I)+0.25*B(31,I))*(Y(J)-Y(J+1))/3.0
      C6=0.5*C6/A(3,I)
      C3=C6*(D(17)*D(23)-D(18)*D(24))
      C4=C6*D(20)
      C5=C6*D(21)
      B(39,I)=-C1-C2-C3
      B(41,I)=-C4
      B(42,I)=C5
      B(43,I)=-C1+2.0*(C2+C3)
      B(45,I)=2.0*C4
      B(46,I)=-2.0*C5
      B(47,I)=B(39,I)
      B(49,I)=-C4
  139 B(50,I)=C5
      GO TO 160
C     TO 149--, LINE-TO-LINE FAULT ON SECONDARY AND PHASE B OF TRANS-
C     FORMER DISCONNECTED FROM THE MAIN BUS.
  140 C4=1.0/(A(2,I)+B(34,I))
      C5=C4*(A(1,I)+B(31,I))
      C4=0.5*C4/A(3,I)
      C1=C4*(D(18)*D(24)-D(16)*D(22))
      C2=C4*D(21)
      C3=C4*D(19)
      B(39,I)=-C5*Y(J)-C1
      B(40,I)=C3
      B(42,I)=-C2
      B(43,I)=B(39,I)
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      B(44,I)=C3
      B(46,I)=-C2
      B(47,I)=-C5*Y(J+2)+2.0*C1
      B(48,I)=-2.0*C3
  149 B(50,I)=2.0*C2
      GO TO 160
C     TO 159--, LINE-TO-LINE FAULT ON SECONDARY AND PHASE C OF TRANS-
C     FORMER DISCONNECTED FROM THE MAIN BUS.
  150 C6=1.0/(A(2,I)+0.25*B(34,I))
      C1=(A(1,I)+B(31,I))*(Y(J)+2.0*Y(J+1))/(3.0*(A(2,I)+B(34,I)))
      C2=C6*(A(1,I)+0.25*B(31,I))*(Y(J)-Y(J+1))/3.0
      C6=0.5*C6/A(3,I)
      C3=C6*(D(16)*D(22)-D(17)*D(23))
      C4=C6*D(19)
      C5=C6*D(20)
      B(39,I)=-C1+2.0*(C3-C2)
      B(40,I)=2.0*C4
      B(41,I)=-2.0*C5
      B(43,I)=-C1+C2-C3
      B(44,I)=-C4
      B(45,I)=C5
      B(47,I)=B(43,I)
      B(48,I)=-C4
  159 B(49,I)=C5
C     COMPUTE THE CONTRIBUTIONS TO THE MATRIX CD.
  160 IF(I.EQ.L(43).AND.L(40).GT.0) GO TO 170
      CD(1,1)=CD(1,1)-(B(48,I)-B(40,I))/A(3,I)
      CD(1,2)=CD(1,2)-(B(49,I)-B(41,I))/A(3,I)
      CD(1,3)=CD(1,3)-(B(50,I)-B(42,I))/A(3,I)
      CD(1,4)=CD(1,4)+(B(47,I)-B(39,I))/A(3,I)
  170 IF(I.EQ.L(43).AND.L(41).GT.0) GO TO 180
      CD(2,1)=CD(2,1)-(B(40,I)-B(44,I))/A(3,I)
      CD(2,2)=CD(2,2)-(B(41,I)-B(45,I))/A(3,I)
      CD(2,3)=CD(2,3)-(B(42,I)-B(46,I))/A(3,I)
      CD(2,4)=CD(2,4)+(B(39,I)-B(43,I))/A(3,I)
  180 IF(I.EQ.L(43).AND.L(42).GT.0) GO TO 200
      CD(3,1)=CD(3,1)-(B(44,I)-B(48,I))/A(3,I)
      CD(3,2)=CD(3,2)-(B(45,I)-B(49,I))/A(3,I)
      CD(3,3)=CD(3,3)-(B(46,I)-B(50,I))/A(3,I)
      CD(3,4)=CD(3,4)+(B(43,I)-B(47,I))/A(3,I)
  200 CONTINUE
      RETURN
      END
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      SUBROUTINE CDCOMP
C     SET UP THE VOLTAGE EQUATIONS OF THE COMMERCIAL POWER SYSTEM.
C     INVERT THESE EQUATIONS TO COMPUTE THE COEFFICIENTS D(100) TO
C     D(111) RELATING THE DERIVATIVES OF THE CURRENTS FROM THE SYSTEM TO
C     THE MAIN BUS TO THE CURRENT DERIVATIVES OF THE RL LOAD OF THE MAIN
C     BUS. THE RUN IS ABORTED IF A SINGULAR MATRIX IS INVOLVED IN THIS
C     INVERSION, AND A COMMENT IS WRITTEN IN TAPE 6.
C     COMPUTE THE CONTRIBUTIONS TO THE MATRIX CD FROM THE SYSTEM.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
    8 FORMAT(1H1,25HABNORMAL EXIT FROM CDCOMP/60H THE EQUATIONS OF THE C
     1OMMERCIAL POWER SYSTEM ARE DEGENERATE)
      NU=L(1)+L(2)+L(3)+L(4)+1
      J=L(NU+50)
      J1=J+1
      J2=J+2
C     TO 20--, COMPUTE THE PHASE VOLTAGES OF THE POWER SYSTEM.
      C1=C(41)
      IF(X.GE.C(43).AND.X.LE.C(45)) C1=C1*(1.0+C(44))
      C2=376.991115*X+C(42)
      D(96)=C1*COS(C2)
      C1=0.866025404*C1*SIN(C2)
      C2=-0.5*D(96)
      D(97)=C2+C1
   20 D(98)=C2-C1
C     TO ABOVE 7--, SET UP VOLTAGE EQUATIONS.
C     TO 70--, GENERAL EXPRESSIONS. SUFFICIENT FOR THREE PHASE FAULT ON
C     PRIMARY OF TRANSFORMER.
      C1=C(35)+2.0*C(37)
      C2=C(36)+2.0*C(38)
      XU1=C1
      XU2=-C(37)
      XU3=-C(37)
      XU4=-C2*Y(J)+C(38)*(Y(J1)+Y(J2))-D(16)*D(22)
      XU5=-D(19)
      XU6=-C(37)
      XU7=C1
      XU8=-C(37)
      XU9=-C2*Y(J1)+C(38)*(Y(J)+Y(J2))-D(17)*D(23)
      XU10=-D(20)
      XU11=-C(37)
      XU12=-C(37)
      XU13=C1
      XU14=-C2*Y(J2)+C(38)*(Y(J)+Y(J1))-D(18)*D(24)
   70 XU15=-D(21)
      IF(X.GE.C(47).AND.X.LE.C(48)) GO TO 2
C     TO 30--, ADJUSTMENTS FOR NO FAULT ON PRIMARY OF TRANSFORMER.
    1 XU1=XU1+2.0*C(39)
      XU2=XU2-C(39)
      XU3=XU3-C(39)
      XU4=XU4-2.0*C(40)*Y(J)+C(40)*(Y(J1)+Y(J2))+D(96)-D(97)
      XU6=XU6-C(39)
      XU7=XU7+2.0*C(39)
      XU8=XU8-C(39)
      XU9=XU9-2.0*C(40)*Y(J1)+C(40)*(Y(J)+Y(J2))+D(97)-D(98)
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      XU11=XU11-C(39)
      XU12=XU12-C(39)
      XU13=XU13+2.0*C(39)
   30 XU14=XU14-2.0*C(40)*Y(J2)+C(40)*(Y(J)+Y(J1))+D(98)-D(96)
      GO TO 7
    2 IF(L(8)-1) 1,3,4
C     TO 40--, ADJUSTMENTS FOR ONE PHASE FAULT ON PRIMARY OF TRANSFORMER
    3 XU1=XU1+C(39)
      XU2=XU2-C(39)
      XU4=XU4-C(40)*(Y(J)-Y(J1))-D(97)
      XU6=XU6-C(39)
      XU7=XU7+2.0*C(39)
      XU8=XU8-C(39)
      XU9=XU9-2.0*C(40)*Y(J1)+C(40)*(Y(J)+Y(J2))+D(97)-D(98)
      XU12=XU12-C(39)
      XU13=XU13+C(39)
   40 XU14=XU14-C(40)*(Y(J2)-Y(J1))+D(98)
      GO TO 7
    4 IF(L(8)-3) 5,7,6
C     TO 50--, ADJUSTMENTS FOR TWO PHASE FAULT ON PRIMARY OF TRANSFORMER
    5 XU7=XU7+C(39)
      XU8=XU8-C(39)
      C1=C(40)*(Y(J2)-Y(J1))-D(98)
      XU9=XU9+C1
      XU12=XU12-C(39)
      XU13=XU13+C(39)
   50 XU14=XU14-C1
      GO TO 7
C     TO 60--, ADJUSTMENTS FOR LINE-TO-LINE FAULT ON PRIMARY OF TRANS-
C     FORMER.
    6 XU7=XU7+1.5*C(39)
      XU8=XU8-1.5*C(39)
      C1=1.5*C(40)*(Y(J1)-Y(J2))+1.5*D(98)
      XU9=XU9-C1
      XU12=XU12-1.5*C(39)
      XU13=XU13+1.5*C(39)
   60 XU14=XU14+C1
C     TO 10--, COMPUTE D(100) TO D(111).
    7 C1=XU7*XU13-XU12*XU8
      C2=XU2*XU13-XU12*XU3
      C3=XU2*XU8-XU7*XU3
      DET=XU1*C1-XU6*C2+XU11*C3
      IF(ABS(DET).GT.1.0E-30) GO TO 9
C     SINGULAR MATRIX. ABORT RUN.
      WRITE(6,8)
      CALL EXIT
    9 D(100)=(XU4*C1-XU9*C2+XU14*C3)/DET
      D(101)=XU5*C1/DET
      D(102)=-XU10*C2/DET
      D(103)=XU15*C3/DET
      C1=(XU6*XU13-XU11*XU8)/DET
      C2=(XU1*XU13-XU11*XU3)/DET
      C3=(XU1*XU8-XU6*XU3)/DET
      D(104)=XU9*C2-XU4*C1-XU14*C3
      D(105)=-XU5*C1
      D(106)=XU10*C2
      D(107)=-XU15*C3
      C1=(XU6*XU12-XU11*XU7)/DET
      C2=(XU1*XU12-XU11*XU2)/DET
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      C3=(XU1*XU7-XU6*XU2)/DET
      D(108)=XU4*C1-XU9*C2+XU14*C3
      D(109)=XU5*C1
      D(110)=-XU10*C2
   10 D(111)=XU15*C3
C     COMPUTE THE CONTRIBUTIONS TO THE MATRIX CD.
      IF(NU.EQ.L(43).AND.L(40).GT.0) GO TO 11
      CD(1,1)=CD(1,1)-D(101)
      CD(1,2)=CD(1,2)-D(102)
      CD(1,3)=CD(1,3)-D(103)
      CD(1,4)=CD(1,4)+D(100)
   11 IF(NU.EQ.L(43).AND.L(41).GT.0) GO TO 12
      CD(2,1)=CD(2,1)-D(105)
      CD(2,2)=CD(2,2)-D(106)
      CD(2,3)=CD(2,3)-D(107)
      CD(2,4)=CD(2,4)+D(104)
   12 IF(NU.EQ.L(43).AND.L(42).GT.0) GO TO 14
      CD(3,1)=CD(3,1)-D(109)
      CD(3,2)=CD(3,2)-D(110)
      CD(3,3)=CD(3,3)-D(111)
      CD(3,4)=CD(3,4)+D(108)
   14 RETURN
      END
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```
      SUBROUTINE CDDR
C     COMPUTE THE CONTRIBUTIONS TO THE MATRIX CD FROM THE DUPLEX REACTOR
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      J=L(31)-5
C     TO 2--, COMPUTE THE INSTANTANEOUS VALUES OF THE PHASE RESISTANCE
C     AND INDUCTANCE OF THE RL LOAD REPRESENTING HVPS NUMBER 2.
      D(77)=C(23)
      D(78)=C(24)
      IF(X.LT.C(29)) GO TO 1
C     TO ABOVE 1--, VALUES FOR STEP CHANGE OF LOAD OF HVPS NUMBER 2.
      C1=1.0+C(30)
      D(77)=C1*D(77)
      D(78)=C1*D(78)
    1 IF(X.LT.C(26).OR.X.GT.C(27)) GO TO 2
C     TO ABOVE 2--, VALUES DURING CROWBAR IN HVPS NUMBER 2.
      D(77)=C(28)
      D(78)=0.0
    2 C1=1.0/(C(19)+C(21))
      C2=1.0/(C(19)+D(77))
      C3=1.0-C(18)*(C1+C2)
      C1=C1/C3
      C2=C2/C3
      C3=C1+C2
      C2=C2*(C(20)+D(78))
      C1=C2-C1*(C(20)+C(22))
      D(79)=C1*Y(J+3)+C2*Y(J)+C3*D(16)*D(22)
      D(80)=C1*Y(J+4)+C2*Y(J+1)+C3*D(17)*D(23)
      D(81)=C1*Y(J+5)+C2*Y(J+2)+C3*D(18)*D(24)
      D(82)=C3
      CD(1,1)=CD(1,1)+C3*D(19)
      CD(1,4)=CD(1,4)-D(79)
      CD(2,2)=CD(2,2)+C3*D(20)
      CD(2,4)=CD(2,4)-D(80)
      CD(3,3)=CD(3,3)+C3*D(21)
      CD(3,4)=CD(3,4)-D(81)
      RETURN
      END
```

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      SUBROUTINE MBSOLV
C     SOLVE FOR THE CURRENT DERIVATIVES OF THE RL LOAD OF THE MAIN BUS
C     BY TRIANGULARIZING THE MATRIX CD.
C     THE RUN IS ABORTED IF THE MATRIX IS SINGULAR, AND A COMMENT IS
C     WRITTEN IN TAPE 6.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
  101 FORMAT(1H1,25HABNORMAL EXIT FROM MBSOLV/26H THE CD MATRIX IS SINGU
     1LAR/1H0,4(1X,E12.5))
      I=4
   37 I=I-1
      IF(ABS(CD(I,I))-1.0E-30) 38,38,45
   38 IF(I-1) 39,39,40
C     SINGULAR MATRIX. ABORT RUN.
   39 WRITE(6,101)((CD(I,J),J=1,4),I=1,3)
      CALL EXIT
   40 I1=I
   41 I1=I1-1
      IF(ABS(CD(I1,I))-1.0E-30) 42,42,43
   42 IF(I1-1) 39,39,41
   43 DO 44 K=1,I
      W1=CD(I,K)
      CD(I,K)=CD(I1,K)
   44 CD(I1,K)=W1
      W1=CD(I,4)
      CD(I,4)=CD(I1,4)
      CD(I1,4)=W1
   45 II=I-1
      IF(II) 48,48,46
   46 DO 47 K=1,II
   47 CD(I,K)=CD(I,K)/CD(I,I)
   48 CD(I,4)=CD(I,4)/CD(I,I)
      IF(II) 75,75,70
   70 I1=I-1
   71 IF(CD(I1,I)) 72,74,72
   72 DO 73 K=1,II
   73 CD(I1,K)=CD(I1,K)-CD(I1,I)*CD(I,K)
      CD(I1,4)=CD(I1,4)-CD(I1,I)*CD(I,4)
   74 I1=I1-1
      IF(I1) 37,37,71
   75 D(25)=CD(1,4)
      D(26)=CD(2,4)-CD(2,1)*D(25)
      D(27)=CD(3,4)-CD(3,1)*D(25)-CD(3,2)*D(26)
      RETURN
      END
```

```
      SUBROUTINE FMACH
C     COMPUTE THE DERIVATIVES OF THE WINDING CURRENTS OF THE ROTATING
C     MACHINES CONNECTED TO THE MAIN BUS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      NS=L(1)+L(2)+L(3)
      DO 61 I=1,NS
      J=L(I+50)
      J1=J+1
      J2=J+2
      J3=J+3
      J4=J+4
      IF(I.NE.L(43).OR.L(40).LE.0) GO TO 51
C     PHASE A OF THE MACHINE IS DISCONNECTED FORM THE MAIN BUS.
      F(J)=0.0
      GO TO 52
   51 F(J)=XL(1,7,I)+XL(1,8,I)*D(25)+XL(1,9,I)*D(26)+XL(1,10,I)*D(27)
   52 IF(I.NE.L(43).OR.L(41).LE.0) GO TO 54
C     PHASE B OF THE MACHINE IS DISCONNECTED FROM THE MAIN BUS.
      F(J1)=0.0
      GO TO 55
   54 F(J1)=XL(2,7,I)+XL(2,8,I)*D(25)+XL(2,9,I)*D(26)+XL(2,10,I)*D(27)-F
     1(J)*XL(2,1,I)
   55 IF(I.NE.L(43).OR.L(42).LE.0) GO TO 58
C     PHASE C OF THE MACHINE IS DISCONNECTED FROM THE MAIN BUS.
      F(J2)=0.0
      GO TO 59
   58 F(J2)=XL(3,7,I)+XL(3,8,I)*D(25)+XL(3,9,I)*D(26)+XL(3,10,I)*D(27)-F
     1(J)*XL(3,1,I)-F(J1)*XL(3,2,I)
   59 F(J3)=XL(4,7,I)+XL(4,8,I)*D(25)+XL(4,9,I)*D(26)+XL(4,10,I)*D(27)-F
     1(J)*XL(4,1,I)-F(J1)*XL(4,2,I)-F(J2)*XL(4,3,I)
      F(J4) = XL(5,7,I) - F(J)*XL(5,1,I) - F(J1)*XL(5,2,I) - F(J2)*XL(5,
     13,I) - F(J3)*XL(5,4,I)
      LI=L(I+99)
      GO TO (60,60,61),LI
   60 J5=J+5
      F(J5) = XL(6,7,I) - F(J)*XL(6,1,I) - F(J1)*XL(6,2,I) - F(J2)*XL(6,
     13,I)
   61 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FTRAN
C     COMPUTE THE DERIVATIVES OF THE DEPENDENT VARIABLES OF THE DISTRI-
C     BUTION TRANSFORMERS CONNECTED TO THE MAIN BUS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      N1=L(1)+L(2)+L(3)+1
      N2=N1+L(4)-1
      DO 100 I=N1,N2
      J=L(I+50)
      F(J)=B(39,I)+B(40,I)*D(25)+B(41,I)*D(26)+B(42,I)*D(27)
      F(J+1)=B(43,I)+B(44,I)*D(25)+B(45,I)*D(26)+B(46,I)*D(27)
      F(J+2)=B(47,I)+B(48,I)*D(25)+B(49,I)*D(26)+B(50,I)*D(27)
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FCOMP
C     COMPUTE THE DERIVATIVES OF THE DEPENDENT VARIABLES OF THE COMMERC-
C     IAL POWER SYSTEM.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      NU = L(1) + L(2) + L(3) + L(4) + 1
      J=L(NU+50)
      J1=J+1
      J2=J+2
      IF(NU.NE.L(43).OR.L(40).LE.0) GO TO 1
C     PHASE A OF THE SYSTEM IS DISCONNECTED FROM THE MAIN BUS.
      F(J)=0.0
      GO TO 2
    1 F(J)=D(100)+D(101)*D(25)+D(102)*D(26)+D(103)*D(27)
    2 IF(NU.NE.L(43).OR.L(41).LE.0) GO TO 3
C     PHASE B OF THE SYSTEM IS DISCONNECTED FROM THE MAIN BUS.
      F(J1)=0.0
      GO TO 4
    3 F(J1)=D(104)+D(105)*D(25)+D(106)*D(26)+D(107)*D(27)
    4 IF(NU.NE.L(43).OR.L(42).LE.0) GO TO 5
C     PHASE C OF THE SYSTEM IS DISCONNECTED FROM THE MAIN BUS.
      F(J2)=0.0
      GO TO 6
    5 F(J2)=D(108)+D(109)*D(25)+D(110)*D(26)+D(111)*D(27)
    6 RETURN
      END
```

```
      SUBROUTINE FDR
C     COMPUTE THE DERIVATIVES OF THE DEPENDENT VARIABLES OF THE DUPLEX
C     REACTOR AND HIGH VOLTAGE POWER SUPPLY NUMBER 1.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      C1=1.0/(2.0*C(19)+C(21)+D(77))
      C2=C1*(C(19)+D(77))
      C3=C1*(C(20)+D(78))
      C1=C1*(C(20)+C(22))+C3
      J = L(31)-5
      J1 = J+3
      F(J)=-D(79)-D(82)*D(19)*D(25)
      F(J1)=-C2*F(J)-C3*Y(J)-C1*Y(J1)
      J=J+1
      J1 = J1+1
      F(J)=-D(80)-D(82)*D(20)*D(26)
      F(J1)=-C2*F(J)-C3*Y(J)-C1*Y(J1)
      J = J+1
      J1 = J1+1
      F(J)=-D(81)-D(82)*D(21)*D(27)
      F(J1)=-C2*F(J)-C3*Y(J)-C1*Y(J1)
      RETURN
      END
```

```
      SUBROUTINE FREG
C     COMPUTE THE DERIVATIVES OF THE DEPENDENT VARIABLES OF THE REGULA-
C     TORS OF THE GENERATING UNITS.
C     COMPUTE THE AVERAGE THREE-PHASE POWERS AND THE PEAK REACTIVE POW-
C     ERS PER PHASE OF THE GENERATING UNITS, AND THEIR CONTRIBUTIONS TO
C     THE LOAD OF THE MAIN BUS. ALSO, COMPUTE THE FIELD FORCING CURRENTS
C     AND THE FIELD VOLTAGES OF THE GENERATING UNITS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      NT=L(1)
C     TO 39--, COMPUTATION OF AVERAGE THREE-PHASE POWERS AND OF PEAK RE-
C     ACTIVE POWERS PER PHASE.
      DO 39 I=1,NT
      J=L(I+50)
      J2=J+1
      J3=J2+1
      B(1,I)=0.001*(D(35)*Y(J)+D(36)*Y(J2)+D(37)*Y(J3))
      B(2,I)=1.9245E-4*(Y(J)*D(39)+Y(J2)*D(40)+Y(J3)*D(38))
      D(3)=D(3)+B(1,I)
      D(4)=D(4)+B(2,I)
   39 CONTINUE
C     TO ABOVE 701--, FOR REACTIVE LOAD SHARE CONTROL.
      SW=10.0
      IF (L(5).LE.0) GO TO 700
      TAP = D(3)-D(5)
      IF(TAP.LE.1.0E-10)GO TO 702
      NU=L(1)+L(2)+L(3)+L(4)+1
      J=L(NU+50)
      CA = D(28)-Y(J)
      CB = D(29) - Y(J+1)
      CC = D(30)-Y(J+2)
      GO TO 701
  700 TAP = D(3)
      IF(TAP.GT.1.0E-10)GO TO 703
  702 SW=0.0
      D38=ABS(D(38))
      D39=ABS(D(39))
      D40=ABS(D(40))
      GO TO 701
  703 CA=D(28)
      CB = D(29)
      CC = D(30)
C     TO 52--, COMPUTE THE DERIVATIVES.
  701 DO 52 I=1,NT
      J=L(I+50)
      J8=J+7
      J9=J+8
      J10=J+9
      J11=J+10
C     TO 704--, COMPUTE THE FIELD FORCING CURRENT AND THE FIELD VOLTAGE.
      B(13,I)=2.0*(A(12,I)+A(31,I))*(B(5,I)*(A(1,I)+A(2,I)+1.5*A(3
     1,I))*(Y(J)*B(19,I)+Y(J+1)*B(23,I)+Y(J+2)*B(21,I))-D(35)*B(20,I)-
     2D(36)*B(24,I)-D(37)*B(22,I))/(3.0*A(31,I)*A(4,I)*B(5,I))
      B(14,I)=A(31,I)*(B(13,I)-Y(J+3))+Y(J8)
  704 IF(ABS(B(14,I)).GT.A(32,I)) B(14,I)=SIGN(A(32,I),B(14,I))
```

```
      F(J9)=(A(29,I)*(B(14,I)-A(36,I))-Y(J9))/A(30,I)+A(37,I)
      F(J8) = (A(27,I)*(A(22,I)-Y(J10)-F(J9))-Y(J8))/A(28,I)
      F(J10)=Y(J11)
C     TO 616--, THREE-PHASE FULL WAVE RECTIFIER AND REACTIVE LOAD SHARE
C     CONTROL.
      IF(SW.LE.0.0) GO TO 616
      XLS=B(1,I)/TAP
      D38 = ABS(D(38)+A(23,I)*(Y(J+2)-XLS*CC))
      D39 = ABS(D(39)+A(23,I)*(Y(J)-XLS*CA))
      D40 = ABS(D(40)+A(23,I)*(Y(J+1)-XLS*CB))
  616 B(12,I) = AMAX1(D38,D39,D40)
   52 F(J11) = (A(24,I)*B(12,I)-A(25,I)*Y(J11)-Y(J10))/A(26,I)
      RETURN
      END
```

```
      SUBROUTINE YPRIMG
C     THIS IS A MAIN SUBROUTINE IN THE COMPUTATION OF THE DERIVATIVES OF
C     THE DEPENDENT VARIABLES OF THE GENERATORS OF THE MG SETS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
C     TO 250--, COMPUTE THE DERIVATIVES OF THE WINDING CURRENTS OF THE
C     SYNCHRONOUS ALTERNATORS.
C     TO 50--, SET UP THE INDUCTANCE AND ((IMPEDANCE)) MATRICES.
      CALL LMATG
      CALL IMATG
      CALL SATG
   50 CALL SATEFG
      CALL RLGB
      N1=L(1)+1
      N2=N1+L(2)-1
C     TO 100--, COMPUTE THE CURRENTS OF THE RL LOADS.
      DO 100 I=N1,N2
      B(86,I)=0.0
      B(87,I)=0.0
      B(88,I)=0.0
      K=L(I+50)+8
      J=I
      IF(A(69,I).LT.0.0) J=J-1
      B(86,J)=B(86,J)+Y(K)
      B(87,J)=B(87,J)+Y(K+1)
  100 B(88,J)=B(88,J)+Y(K+2)
      CALL XMMAT
      CALL TRIAG
C     TO 200--, SET UP THE MATRIX GB CONTAINING THE COEFFICIENTS OF THE
C     EQUATIONS RELATING THE CURRENT DERIVATIVES OF THE RL LOADS.
      DO 120 I=N1,N2
      J=I-L(1)
      DO 120 K=1,3
      DO 120 M=1,4
  120 GB(K,M,J)=0.0
      CALL GBMAT
      DO 200 I=N1,N2
      IF(A(69,I).LT.0.0) GO TO 200
      J=I-L(1)
      IF(X.LT.A(75,I).OR.X.GT.A(76,I)) GO TO 150
C     TO 130--, ADJUST MATRIX GB DURING LINE-TO-LINE FAULTS ON BUSES OF
C     MG SETS.
      K=IFIX(A(77,I)+0.00000001)
      IF(K.LE.3) GO TO 150
      GB(2,1,J)=GB(2,1,J)+GB(1,1,J)+1.0
      GB(2,2,J)=GB(2,2,J)+GB(1,2,J)+1.0
      GB(2,3,J)=GB(2,3,J)+GB(1,3,J)
      GB(2,4,J)=GB(2,4,J)+GB(1,4,J)
      GB(3,3,J)=GB(3,3,J)+1.0
      GB(1,1,J)=B(83,I)
      GB(1,2,J)=-B(84,I)
      GB(1,3,J)=0.0
  130 GB(1,4,J)=B(81,I)*B(87,I)-B(80,I)*B(86,I)
      GO TO 200
  150 GB(1,1,J)=GB(1,1,J)+1.0
```

```
      GB(2,2,J)=GB(2,2,J)+1.0
      GB(3,3,J)=GB(3,3,J)+1.0
  200 CONTINUE
      CALL GBSOLV
  250 CALL FGEN
C     TO 300--, COMPUTE THE PHASE AND LINE-TO-LINE VOLTAGES OF THE BUSES
C     OF THE MG SETS.
      DO 300 I=N1,N2
      IF(A(69,I).LT.0.0) GO TO 300
      B(74,I)=B(80,I)*B(86,I)+B(83,I)*B(89,I)
      B(75,I)=B(81,I)*B(87,I)+B(84,I)*B(90,I)
      B(76,I)=B(82,I)*B(88,I)+B(85,I)*B(91,I)
      B(77,I)=B(74,I)-B(75,I)
      B(78,I)=B(75,I)-B(76,I)
      B(79,I)=B(76,I)-B(74,I)
  300 CONTINUE
      CALL FREGG
      RETURN
      END
```

```
      SUBROUTINE LMATG
C     SET UP THE INDUCTANCE MATRICES, WITHOUT FIELD SATURATION EFFECTS,
C     OF THE SYNCHRONOUS ALTERNATORS OF THE MG SETS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      CC=0.866025404
      N1=L(1)+1
      N2=N1+L(2)-1
      DO 10 I=N1,N2
      J=I-L(1)
      K=L(I+50)+14
      XM(1,1,J)=A(31,I)
      XM(2,1,J)=-A(32,I)
      XM(3,1,J)=XM(2,1,J)
      XM(2,2,J)=XM(1,1,J)
      XM(3,2,J)=XM(2,1,J)
      XM(3,3,J)=XM(1,1,J)
      B(49,I)=COS(Y(K))
      B(50,I)=SIN(Y(K))
      C1=0.5*B(49,I)
      C2=CC*B(49,I)
      C3=0.5*B(50,I)
      C4=CC*B(50,I)
      B(51,I)=-C1-C4
      B(52,I)=-C3+C2
      B(53,I)=-C1+C4
      B(54,I)=-C3-C2
      XM(4,1,J)=-A(34,I)*B(49,I)
      XM(4,2,J)=-A(34,I)*B(53,I)
      XM(4,3,J)=-A(34,I)*B(51,I)
      XM(4,4,J)=A(37,I)
      XM(5,1,J)=-A(35,I)*B(49,I)
      XM(5,2,J)=-A(35,I)*B(53,I)
      XM(5,3,J)=-A(35,I)*B(51,I)
      XM(5,4,J)=A(38,I)
      XM(5,5,J)=A(39,I)
      XM(6,1,J)=A(36,I)*B(50,I)
      XM(6,2,J)=A(36,I)*B(54,I)
      XM(6,3,J)=A(36,I)*B(52,I)
      IF(A(33,I).LE.0.0) GO TO 8
C     TO ABOVE 8--, SALIENCY EFFECTS.
      B(55,I)=2.0*B(49,I)*B(49,I)-1.0
      B(56,I)=2.0*B(49,I)*B(50,I)
      C1=0.5*B(55,I)
      C2=CC*B(55,I)
      C3=0.5*B(56,I)
      C4=CC*B(56,I)
      B(57,I)=-C1-C4
      B(58,I)=-C3+C2
      B(59,I)=-C1+C4
      B(60,I)=-C3-C2
      XM(1,1,J)=XM(1,1,J)+A(33,I)*B(55,I)
      XM(2,1,J)=XM(2,1,J)+A(33,I)*B(59,I)
      XM(3,1,J)=XM(3,1,J)+A(33,I)*B(57,I)
      XM(2,2,J)=XM(2,2,J)+A(33,I)*B(57,I)
```

```
      XM(3,2,J)=XM(3,2,J)+A(33,I)*B(55,I)
      XM(3,3,J)=XM(3,3,J)+A(33,I)*B(59,I)
    8 XM(1,2,J)=XM(2,1,J)
      XM(1,3,J)=XM(3,1,J)
      XM(1,4,J)=XM(4,1,J)
      XM(1,5,J)=XM(5,1,J)
      XM(2,3,J)=XM(3,2,J)
      XM(2,4,J)=XM(4,2,J)
      XM(2,5,J)=XM(5,2,J)
      XM(3,4,J)=XM(4,3,J)
      XM(3,5,J)=XM(5,3,J)
      XM(4,5,J)=XM(5,4,J)
      XM(1,6,J)=XM(6,1,J)
      XM(2,6,J)=XM(6,2,J)
      XM(3,6,J)=XM(6,3,J)
      XM(4,6,J)=XM(6,4,J)
      XM(5,6,J)=XM(6,5,J)
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE IMATG
C     SET UP THE ((IMPEDANCE)) MATRICES, WITHOUT FIELD SATURATION EF-
C     FECTS, OF THE SYNCHRONOUS ALTERNATORS OF THE MG SETS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      N1=L(1)+1
      N2=N1+L(2)-1
      DO 10 I=N1,N2
      J=I-L(1)
      IF(A(33,I).LE.0.0) GO TO 3
C     TO ABOVE 3--, SALIENCY EFFECTS.
      CC=-2.0*A(33,I)*B(5,I)
      W(2,1,J)=CC*B(60,I)
      W(3,1,J)=CC*B(58,I)
      W(3,2,J)=CC*B(56,I)
      W(1,1,J)=A(41,I)+W(3,2,J)
      W(2,2,J)=A(41,I)+W(3,1,J)
      W(3,3,J)=A(41,I)+W(2,1,J)
      GO TO 4
    3 W(1,1,J)=A(41,I)
      W(2,1,J)=0.0
      W(3,1,J)=0.0
      W(2,2,J)=A(41,I)
      W(3,2,J)=0.0
      W(3,3,J)=A(41,I)
    4 CC=A(34,I)*B(5,I)
      W(4,1,J)=CC*B(50,I)
      W(4,2,J)=CC*B(54,I)
      W(4,3,J)=CC*B(52,I)
      CC=A(35,I)*B(5,I)
      W(5,1,J)=CC*B(50,I)
      W(5,2,J)=CC*B(54,I)
      W(5,3,J)=CC*B(52,I)
      CC=A(36,I)*B(5,I)
      W(6,1,J)=CC*B(49,I)
      W(6,2,J)=CC*B(53,I)
      W(6,3,J)=CC*B(51,I)
      W(1,4,J)=W(4,1,J)
      W(1,5,J)=W(5,1,J)
      W(2,4,J)=W(4,2,J)
      W(2,5,J)=W(5,2,J)
      W(3,4,J)=W(4,3,J)
      W(3,5,J)=W(5,3,J)
      W(1,2,J)=W(2,1,J)
      W(1,3,J)=W(3,1,J)
      W(2,3,J)=W(3,2,J)
      W(1,6,J)=W(6,1,J)
      W(2,6,J)=W(6,2,J)
      W(3,6,J)=W(6,3,J)
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SATG
C     DETERMINE IF THE FIELDS OF THE SYNCHRONOUS ALTERNATORS OF THE MG
C     SETS ARE SATURATED, AND COMPUTE THE FIELD FLUX LINKAGES, THE EQUI-
C     VALENT FIELD SATURATION CURRENTS, AND THE DERIVATIVES OF THE
C     LATTER WITH RESPECT TO THE FORMER.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      N1=L(1)+1
      N2=N1+L(2)-1
      DO 10 I=N1,N2
      J=L(I+50)+7
      B(34,I)=0.0
      N=I-L(1)
      DO 4 K=1,5
      M=J+K
    4 B(34,I)=B(34,I)+XM(4,K,N)*Y(M)
      IF(B(34,I).GT.A(45,I)) GO TO 6
      B(35,I)=0.0
      B(36,I)=0.0
      L(N+86)=1
      GO TO 10
    6 C1=A(45,I)-0.5/(A(46,I)*A(37,I))
      C2=C1*C1+B(34,I)/(A(46,I)*A(37,I))-A(45,I)*A(45,I)
      C2=SQRT(C2)
      B(34,I)=C1+C2
      B(35,I)=A(46,I)*(B(34,I)-A(45,I))*(B(34,I)-A(45,I))
      B(36,I)=2.0*A(46,I)*(B(34,I)-A(45,I))
      L(N+86)=2
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SATEFG
C     ADD THE FIELD SATURATION EFFECTS TO THE INDUCTANCE AND ((IMPED-
C     ANCE)) MATRICES OF THE SYNCHRONOUS ALTERNATORS OF THE MG SETS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      N1=L(1)+1
      N2=N1+L(2)-1
      DO 10 I=N1,N2
      J=I-L(1)
      L80=L(J+86)
      GO TO (10,5),L80
    5 C1=A(34,I)*B(36,I)/(1.0+A(37,I)*B(36,I))
      C2=C1*A(34,I)
      C3=C1*B(49,I)
      C4=C2*B(49,I)
      XM(1,1,J)=XM(1,1,J)-C4*B(49,I)
      XM(2,1,J)=XM(2,1,J)-C4*B(53,I)
      XM(3,1,J)=XM(3,1,J)-C4*B(51,I)
      XM(4,1,J)=XM(4,1,J)+C3*A(37,I)
      XM(5,1,J)=XM(5,1,J)+C3*A(38,I)
      C3=C1*B(53,I)
      C4=C2*B(53,I)
      XM(2,2,J)=XM(2,2,J)-C4*B(53,I)
      XM(3,2,J)=XM(3,2,J)-C4*B(51,I)
      XM(4,2,J)=XM(4,2,J)+C3*A(37,I)
      XM(5,2,J)=XM(5,2,J)+C3*A(38,I)
      XM(3,3,J)=XM(3,3,J)-C2*B(51,I)*B(51,I)
      C3=C1*B(51,I)
      XM(4,3,J)=XM(4,3,J)+C3*A(37,I)
      XM(5,3,J)=XM(5,3,J)+C3*A(38,I)
      C3=C1*A(37,I)/A(34,I)
      XM(4,4,J)=XM(4,4,J)-C3*A(37,I)
      XM(5,4,J)=XM(5,4,J)-C3*A(38,I)
      XM(5,5,J)=XM(5,5,J)-C1*A(38,I)*A(38,I)/A(34,I)
      C1=C1*B(5,I)
      C2=C2*B(5,I)
      C3=C1*B(50,I)
      C4=C2*B(50,I)
      W(1,1,J)=W(1,1,J)+C4*B(49,I)
      W(2,1,J)=W(2,1,J)+C4*B(53,I)
      W(3,1,J)=W(3,1,J)+C4*B(51,I)
      W(4,1,J)=W(4,1,J)-C3*A(37,I)
      W(5,1,J)=W(5,1,J)-C3*A(38,I)
      C3=C1*B(54,I)
      C4=C2*B(54,I)
      W(1,2,J)=W(1,2,J)+C4*B(49,I)
      W(2,2,J)=W(2,2,J)+C4*B(53,I)
      W(3,2,J)=W(3,2,J)+C4*B(51,I)
      W(4,2,J)=W(4,2,J)-C3*A(37,I)
      W(5,2,J)=W(5,2,J)-C3*A(38,I)
      C3=C1*B(52,I)
      C4=C2*B(52,I)
      W(1,3,J)=W(1,3,J)+C4*B(49,I)
      W(2,3,J)=W(2,3,J)+C4*B(53,I)
      W(3,3,J)=W(3,3,J)+C4*B(51,I)
```

```
      W(4,3,J)=W(4,3,J)-C3*A(37,I)
      W(5,3,J)=W(5,3,J)-C3*A(38,I)
      XM(1,2,J)=XM(2,1,J)
      XM(1,3,J)=XM(3,1,J)
      XM(1,4,J)=XM(4,1,J)
      XM(1,5,J)=XM(5,1,J)
      XM(2,3,J)=XM(3,2,J)
      XM(2,4,J)=XM(4,2,J)
      XM(2,5,J)=XM(5,2,J)
      XM(3,4,J)=XM(4,3,J)
      XM(3,5,J)=XM(5,3,J)
      XM(4,5,J)=XM(5,4,J)
      C1=A(34,I)*B(5,I)
      B(37,I)=C1*B(50,I)
      B(38,I)=C1*B(54,I)
      B(39,I)=C1*B(52,I)
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE RLGB
C     COMPUTE THE INSTANTANEOUS VALUES OF THE PHASE RESISTANCES AND IN-
C     DUCTANCES OF THE RL LOADS OF THE MG SETS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      N1=L(1)+1
      N2=N1+L(2)-1
      DO 100 I=N1,N2
      C1=A(70,I)
      C2=A(71,I)
      DO 10 J=80,82
      B(J+3,I)=C2
   10 B(J,I)=C1
      IF(X.LT.A(73,I)) GO TO 20
C     TO 15--, STEP CHANGES IN THE RL LOADS.
      C1=1.0+A(74,I)
      DO 15 J=80,85
   15 B(J,I)=C1*B(J,I)
   20 IF(X.LT.A(78,I)) GO TO 30
C     TO 25--, SINUSOIDAL VARIATIONS OF THE RL LOADS.
      C1=A(79,I)*(X-A(78,I))
      C2=1.0+A(80,I)*SIN(C1)
      C1=A(79,I)*A(80,I)*COS(C1)
      DO 25 J=80,82
      K=J+3
      B(J,I)=C2*B(J,I)+C1*B(K,I)
   25 B(K,I)=C2*B(K,I)
   30 IF(X.LT.A(75,I).OR.X.GT.A(76,I)) GO TO 100
C     TO 100--, ADJUST VALUES DURING ONE, TWO, OR THREE PHASE FAULTS ON
C     BUSES OF MG SETS.
      K=IFIX(A(77,I)+0.00000001)
      IF(K.LE.0.OR.K.GT.3) GO TO 100
      GO TO (70,60,50),K
   50 B(82,I)=0.0
      B(85,I)=0.0
   60 B(81,I)=0.0
      B(84,I)=0.0
   70 B(80,I)=0.0
      B(83,I)=0.0
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE XMMAT
C     SET UP THE MATRIX XM CONTAINING THE COEFFICIENTS OF THE EQUATIONS
C     RELATING THE WINDING CURRENT DERIVATIVES OF THE SYNCHRONOUS ALTER-
C     NATORS OF THE MG SETS TO THE CURRENT DERIVATIVES OF THE RL LOADS
C     OF THE RESPECTIVE BUSES.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      N1=L(1)+1
      N2=N1+L(2)-1
      DO 100 I=N1,N2
      J=L(I+50)+8
      K=I-L(1)
      M=I
      IF(A(69,I).LT.0.0) M=M-1
      C1=B(80,M)*B(86,M)
      C2=B(81,M)*B(87,M)
      C3=B(82,M)*B(88,M)
C     TO 2--, CONTRIBUTIONS FROM THE GROUNDING REACTORS.
      C4=A(61,I)
      IF(C4.LE.0.0) GO TO 3
      DO 2 I1=1,3
      DO 2 I2=1,3
    2 XM(I1,I2,K)=XM(I1,I2,K)+C4
    3 DO 10 I1=1,6
      DO 5 I2=7,10
    5 XM(I1,I2,K)=0.0
   10 CONTINUE
      XM(1,7,K)=-C1+B(35,I)*B(37,I)
      XM(1,8,K)=-B(83,M)
      XM(2,7,K)=-C2+B(35,I)*B(38,I)
      XM(2,9,K)=-B(84,M)
      XM(3,7,K)=-C3+B(35,I)*B(39,I)
      XM(3,10,K)=-B(85,M)
C     TO 35--, CONTRIBUTIONS FROM THE FIELD VOLTAGE. (EXCITER MODEL.)
      IF(ABS(Y(J+7)).GT.A(60,I)) Y(J+7)=SIGN(A(60,I),Y(J+7))
      IF(ABS(B(42,I)).LT.A(59,I)) GO TO 30
      XM(4,7,K)=SIGN(A(59,I),B(42,I))
      GO TO 40
   30 C4=2.0*(A(42,I)+A(58,I))/(3.0*A(34,I)*B(5,I))
      C5=C4*(A(31,I)+A(32,I)+1.5*A(33,I))*B(5,I)
      XM(4,7,K)=C5*(Y(J)*B(49,I)+Y(J+1)*B(53,I)+Y(J+2)*B(51,I))-C4*(B(80
     1,M)*B(86,M)*B(50,I)+B(81,M)*B(87,M)*B(54,I)+B(82,M)*B(88,M)*B(52,I
     2))+Y(J+7)-A(58,I)*Y(J+3)
      XM(4,8,K)=-C4*B(83,M)*B(50,I)
      XM(4,9,K)=-C4*B(84,M)*B(54,I)
   35 XM(4,10,K)=-C4*B(85,M)*B(52,I)
   40 DO 60 I1=1,6
      DO 50 I2=1,6
      N=J+I2-1
   50 XM(I1,7,K)=XM(I1,7,K)-W(I1,I2,K)*Y(N)
   60 CONTINUE
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TRIAG
C     FOR EACH SYNCHRONOUS ALTERNATOR OF THE MG SETS, TRIANGULARIZE THE
C     CORRESPONDING PART OF THE MATRIX XM.
C     THE RUN IS ABORTED IF ANY SUCH PART OF XM IS SINGULAR, AND A COM-
C     MENT IS WRITTEN IN TAPE 6.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
  100 FORMAT(1H1,24HABNORMAL EXIT FROM TRIAG/31H THE XM MATRIX OF MG SET
     1 NUMBER,I3,12H IS SINGULAR)
      NS=L(2)
      DO 23 I=1,NS
      J=7
    3 J=J-1
      IF(ABS(XM(J,J,I))-1.0E-30) 4,4,12
    4 IF(J-1) 5,5,6
C     SINGULAR MATRIX. ABORT RUN.
    5 WRITE(6,100) I
      CALL EXIT
    6 J1=J
    7 J1=J1-1
      IF(ABS(XM(J1,J,I))-1.0E-30) 8,8,9
    8 IF(J1-1) 5,5,7
    9 DO 10 K=1,J
      W1=XM(J,K,I)
      XM(J,K,I)=XM(J1,K,I)
   10 XM(J1,K,I)=W1
      DO 11 K=7,10
      W1=XM(J,K,I)
      XM(J,K,I)=XM(J1,K,I)
   11 XM(J1,K,I)=W1
   12 JJ=J-1
      IF(JJ) 15,15,13
   13 DO 14 K=1,JJ
   14 XM(J,K,I)=XM(J,K,I)/XM(J,J,I)
   15 DO 16 K=7,10
   16 XM(J,K,I)=XM(J,K,I)/XM(J,J,I)
      IF(JJ) 23,23,17
   17 J1=J-1
   18 IF(XM(J1,J,I)) 19,22,19
   19 DO 20 K=1,JJ
   20 XM(J1,K,I)=XM(J1,K,I)-XM(J1,J,I)*XM(J,K,I)
      DO 21 K=7,10
   21 XM(J1,K,I)=XM(J1,K,I)-XM(J1,J,I)*XM(J,K,I)
   22 J1=J1-1
      IF(J1) 3,3,18
   23 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE GBMAT
C     FOR EACH BUS OF THE MG SETS, COMPUTE THE CONTRIBUTIONS TO THE COR-
C     RESPONDING PART OF THE MATRIX GB FROM THE SYNCHRONOUS ALTERNATORS
C     CONNECTED TO THE BUS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      N1=L(1)+1
      N2=N1+L(2)-1
      DO 35 I=N1,N2
      J=I-L(1)
      K=J
      IF(A(69,I).LT.0.0) K=K-1
      M=IFIX(B(98,I)+0.1)
      IF(I-M) 33,24,33
   24 IF(B(95,I)) 25,25,27
   25 GB(1,1,K)=GB(1,1,K)-XM(1,8,J)
      GB(1,2,K)=GB(1,2,K)-XM(1,9,J)
      GB(1,3,K)=GB(1,3,K)-XM(1,10,J)
      GB(1,4,K)=GB(1,4,K)+XM(1,7,J)
      IF(B(96,I)) 26,26,31
   26 GB(2,1,K)=GB(2,1,K)-XM(2,8,J)+XM(2,1,J)*XM(1,8,J)
      GB(2,2,K)=GB(2,2,K)-XM(2,9,J)+XM(2,1,J)*XM(1,9,J)
      GB(2,3,K)=GB(2,3,K)-XM(2,10,J)+XM(2,1,J)*XM(1,10,J)
      GB(2,4,K)=GB(2,4,K)+XM(2,7,J)-XM(2,1,J)*XM(1,7,J)
      IF(B(97,I)) 34,34,35
   27 IF(B(96,I)) 28,28,30
C     FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE B WHEN PHASE A OF AN
C     ALTERNATOR IS DISCONNECTED FROM THE BUS.
   28 GB(2,1,K)=GB(2,1,K)-XM(2,8,J)
      GB(2,2,K)=GB(2,2,K)-XM(2,9,J)
      GB(2,3,K)=GB(2,3,K)-XM(2,10,J)
      GB(2,4,K)=GB(2,4,K)+XM(2,7,J)
      IF(B(97,I)) 29,29,35
C     FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE C WHEN ONLY PHASE A OF
C     AN ALTERNATOR IS DISCONNECTED FROM THE BUS.
   29 GB(3,1,K)=GB(3,1,K)-XM(3,8,J)+XM(3,2,J)*XM(2,8,J)
      GB(3,2,K)=GB(3,2,K)-XM(3,9,J)+XM(3,2,J)*XM(2,9,J)
      GB(3,3,K)=GB(3,3,K)-XM(3,10,J)+XM(3,2,J)*XM(2,10,J)
      GB(3,4,K)=GB(3,4,K)+XM(3,7,J)-XM(3,2,J)*XM(2,7,J)
      GO TO 35
C     FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE C WHEN PHASES A AND B
C     OF AN ALTERNATOR ARE DISCONNECTED FROM THE BUS.
   30 IF(B(97,I).GT.0.0) GO TO 35
      GB(3,1,K)=GB(3,1,K)-XM(3,8,J)
      GB(3,2,K)=GB(3,2,K)-XM(3,9,J)
      GB(3,3,K)=GB(3,3,K)-XM(3,10,J)
      GB(3,4,K)=GB(3,4,K)+XM(3,7,J)
      GO TO 35
   31 IF(B(97,I)) 32,32,35
C     FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE C WHEN ONLY PHASE B OF
C     AN ALTERNATOR IS DISCONNECTED FROM THE BUS.
   32 GB(3,1,K)=GB(3,1,K)-XM(3,8,J)+XM(3,1,J)*XM(1,8,J)
      GB(3,2,K)=GB(3,2,K)-XM(3,9,J)+XM(3,1,J)*XM(1,9,J)
      GB(3,3,K)=GB(3,3,K)-XM(3,10,J)+XM(3,1,J)*XM(1,10,J)
      GB(3,4,K)=GB(3,4,K)+XM(3,7,J)-XM(3,1,J)*XM(1,7,J)
```

```
      GO TO 35
   33 GB(1,1,K)=GB(1,1,K)-XM(1,8,J)
      GB(1,2,K)=GB(1,2,K)-XM(1,9,J)
      GB(1,3,K)=GB(1,3,K)-XM(1,10,J)
      GB(1,4,K)=GB(1,4,K)+XM(1,7,J)
      GB(2,1,K)=GB(2,1,K)-XM(2,8,J)+XM(2,1,J)*XM(1,8,J)
      GB(2,2,K)=GB(2,2,K)-XM(2,9,J)+XM(2,1,J)*XM(1,9,J)
      GB(2,3,K)=GB(2,3,K)-XM(2,10,J)+XM(2,1,J)*XM(1,10,J)
      GB(2,4,K)=GB(2,4,K)+XM(2,7,J)-XM(2,1,J)*XM(1,7,J)
   34 GB(3,1,K)=GB(3,1,K)-XM(3,8,J)+XM(3,2,J)*XM(2,8,J)+XM(1,8,J)*(XM(3,
     11,J)-XM(2,1,J)*XM(3,2,J))
      GB(3,2,K)=GB(3,2,K)-XM(3,9,J)+XM(3,2,J)*XM(2,9,J)+XM(1,9,J)*(XM(3,
     11,J)-XM(2,1,J)*XM(3,2,J))
      GB(3,3,K)=GB(3,3,K)-XM(3,10,J)+XM(3,2,J)*XM(2,10,J)+XM(1,10,J)*(XM
     1(3,1,J)-XM(2,1,J)*XM(3,2,J))
      GB(3,4,K)=GB(3,4,K)+XM(3,7,J)-XM(3,2,J)*XM(2,7,J)-XM(1,7,J)*(XM(3,
     11,J)-XM(2,1,J)*XM(3,2,J))
   35 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE GBSOLV
C     SOLVE FOR THE CURRENT DERIVATIVES OF THE RL LOADS OF THE BUSES OF
C     THE MG SETS BY TRIANGULARIZING THE CORRESPONDING PARTS OF THE
C     MATRIX GB.
C     THE RUN IS ABORTED IF ANY SUCH PART OF THE MATRIX GB IS SINGULAR,
C     AND A COMMENT IS WRITTEN IN TAPE 6.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
  101 FORMAT(1H1,25HABNORMAL EXIT FROM GBSOLV/31H THE GB MATRIX OF MG BU
     1S NUMBER,I3,12H IS SINGULAR/1H0,4(1X,E12.5))
      L2=L(2)
      DO 100 K=1,L2
      J=K+L(1)
      IF(A(69,J).LT.0.0) GO TO 100
      I=4
   37 I=I-1
      IF(ABS(GB(I,I,K))-1.0E-30) 38,38,45
   38 IF(I-1) 39,39,40
C     SINGULAR MATRIX. ABORT RUN.
   39 WRITE(6,101) K,((GB(I,M,K),M=1,4),I=1,3)
      CALL EXIT
   40 I1=I
   41 I1=I1-1
      IF(ABS(GB(I1,I,K))-1.0E-30) 42,42,43
   42 IF(I1-1) 39,39,41
   43 DO 44 M=1,I
      W1=GB(I,M,K)
      GB(I,M,K)=GB(I1,M,K)
   44 GB(I1,M,K)=W1
      W1=GB(I,4,K)
      GB(I,4,K)=GB(I1,4,K)
      GB(I1,4,K)=W1
   45 II=I-1
      IF(II) 48,48,46
   46 DO 47 M=1,II
   47 GB(I,M,K)=GB(I,M,K)/GB(I,I,K)
   48 GB(I,4,K)=GB(I,4,K)/GB(I,I,K)
      IF(II) 75,75,70
   70 I1=I-1
   71 IF(GB(I1,I,K)) 72,74,72
   72 DO 73 M=1,II
   73 GB(I1,M,K)=GB(I1,M,K)-GB(I1,I,K)*GB(I,M,K)
      GB(I1,4,K)=GB(I1,4,K)-GB(I1,I,K)*GB(I,4,K)
   74 I1=I1-1
      IF(I1) 37,37,71
   75 B(89,J)=GB(1,4,K)
      B(90,J)=GB(2,4,K)-GB(2,1,K)*B(89,J)
      B(91,J)=GB(3,4,K)-GB(3,1,K)*B(89,J)-GB(3,2,K)*B(90,J)
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FGEN
C     COMPUTE THE DERIVATIVES OF THE WINDING CURRENTS OF THE ALTERNATORS
C     OF THE MG SETS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      N1=L(1)+1
      N2=N1+L(2)-1
      DO 61 I=N1,N2
      J=L(I+50)+8
      J1=J+1
      J2=J+2
      J3=J+3
      J4=J+4
      J5=J+5
      K=I-L(1)
      N=I
      IF(A(69,I).LT.0.0) N=N-1
      L43=IFIX(B(98,I)+0.1)
      IF(I.NE.L43.OR.B(95,I).LE.0.0) GO TO 51
C     PHASE A OF ALTERNATOR IS DISCONNECTED FROM BUS.
      F(J)=0.0
      GO TO 52
   51 F(J)=XM(1,7,K)+XM(1,8,K)*B(89,N)+XM(1,9,K)*B(90,N)+XM(1,10,K)*B(91
     1,N)
   52 IF(I.NE.L43.OR.B(96,I).LE.0.0) GO TO 54
C     PHASE B OF ALTERNATOR IS DISCONNECTED FROM BUS.
      F(J1)=0.0
      GO TO 55
   54 F(J1)=XM(2,7,K)+XM(2,8,K)*B(89,N)+XM(2,9,K)*B(90,N)+XM(2,10,K)*B(9
     11,N)-F(J)*XM(2,1,K)
   55 IF(I.NE.L43.OR.B(97,I).LE.0.0) GO TO 58
C     PHASE C OF ALTERNATOR IS DISCONNECTED FROM BUS.
      F(J2)=0.0
      GO TO 59
   58 F(J2)=XM(3,7,K)+XM(3,8,K)*B(89,N)+XM(3,9,K)*B(90,N)+XM(3,10,K)*B(9
     11,N)-F(J)*XM(3,1,K)-F(J1)*XM(3,2,K)
   59 F(J3)=XM(4,7,K)+XM(4,8,K)*B(89,N)+XM(4,9,K)*B(90,N)+XM(4,10,K)*B(9
     11,N)-F(J)*XM(4,1,K)-F(J1)*XM(4,2,K)-F(J2)*XM(4,3,K)
      F(J4)=XM(5,7,K)-F(J)*XM(5,1,K)-F(J1)*XM(5,2,K)-F(J2)*XM(5,3,K)-F(J
     13)*XM(5,4,K)
      F(J5)=XM(6,7,K)-F(J)*XM(6,1,K)-F(J1)*XM(6,2,K)-F(J2)*XM(6,3,K)
   61 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FREGG
C     COMPUTE THE DERIVATIVES OF THE DEPENDENT VARIABLES OF THE REGULA-
C     TORS OF THE GENERATORS OF THE MG SETS.
C     COMPUTE THE AVERAGE THREE-PHASE POWERS AND THE PEAK REACTIVE POW-
C     ERS PER PHASE OF THE GENERATORS OF THE MG SETS, AND THEIR CONTRI-
C     BUTIONS TO THE BUS LOADS. ALSO, COMPUTE THE FIELD FORCING CURRENTS
C     AND FIELD VOLTAGES OF THE GENERATORS OF THE MG SETS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      N1=L(1)+1
      N2=N1+L(2)-1
C     TO 100--, COMPUTATION OF AVERAGE THREE-PHASE POWERS AND OF PEAK
C     REACTIVE POWERS PER PHASE.
      DO 100 I=N1,N2
      J=L(I+50)+8
      J2=J+1
      J3=J2+1
      K=I
      IF(A(69,I).LT.0.0) K=K-1
      B(31,I)=0.001*(B(74,K)*Y(J)+B(75,K)*Y(J2)+B(76,K)*Y(J3))
      B(32,I)=1.9245E-4*(B(78,K)*Y(J)+B(79,K)*Y(J2)+B(77,K)*Y(J3))
      B(61,I)=0.0
      B(62,I)=0.0
      B(61,K)=B(61,K)+B(31,I)
      B(62,K)=B(62,K)+B(32,I)
  100 CONTINUE
C     TO 200--, COMPUTE THE DERIVATIVES.
      DO 200 I=N1,N2
      J=L(I+50)+8
      J2=J+1
      J3=J2+1
      J8=J+7
      J9=J8+1
      J10=J9+1
      J11=J10+1
      K=I
      IF(A(69,I).LT.0.0) K=K-1
C     TO 120--, COMPUTE THE FIELD FORCING CURRENT AND THE FIELD VOLTAGE.
      B(41,I)=2.0*(A(42,I)+A(58,I))*(B(5,I)*(A(31,I)+A(32,I)+1.5*A(33,I)
     1)*(Y(J)*B(49,I)+Y(J2)*B(53,I)+Y(J3)*B(51,I))-B(74,K)*B(50,I)-B(75,
     2K)*B(54,I)-B(76,K)*B(52,I))/(3.0*A(58,I)*A(34,I)*B(5,I))
      B(42,I)=A(58,I)*(B(41,I)-Y(J+3))+Y(J8)
  120 IF(ABS(B(42,I)).GT.A(59,I)) B(42,I)=SIGN(A(59,I),B(42,I))
      F(J9)=(A(56,I)*(B(42,I)-A(66,I))-Y(J9))/A(57,I)+A(67,I)
      F(J8)=(A(54,I)*(A(49,I)-Y(J10)-F(J9))-Y(J8))/A(55,I)
      F(J10)=Y(J11)
C     TO 180--, THREE-PHASE FULL WAVE RECTIFIER AND REACTIVE LOAD SHARE
C     CONTROL.
      IF(B(61,K).GT.1.0E-10) GO TO 150
      B77=ABS(B(77,K))
      B78=ABS(B(78,K))
      B79=ABS(B(79,K))
      GO TO 180
  150 XLS=B(31,I)/B(61,K)
      B77=ABS(B(77,K)+A(50,I)*(Y(J3)-XLS*B(88,K)))
```

```
      B78=ABS(B(78,K)+A(50,I)*(Y(J)-XLS*B(86,K)))
      B79=ABS(B(79,K)+A(50,I)*(Y(J2)-XLS*B(87,K)))
  180 B(40,I)=AMAX1(B77,B78,B79)
  200 F(J11)=(A(51,I)*B(40,I)-A(52,I)*Y(J11)-Y(J10))/A(53,I)
      RETURN
      END
```

```
      SUBROUTINE FMECH
C     COMPUTE THE DERIVATIVES OF THE MECHANICAL SPEEDS OF THE SHAFTS OF
C     THE MG SETS AND OF THE INDUCTION MOTORS.
C     ALSO, COMPUTE THE DERIVATIVES OF THE ELECTRICAL ANGLES OF ALL RO-
C     TATING MACHIVES OF THE POWER PLANT.
C     COMPUTE THE EM TORQUES OF ALL ROTATING MACHINES OF THE POWER PLANT
C     EXCEPT THOSE OF THE GENERATING UNITS.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
      IF(L(3).GT.0) CALL TORIM
      NS=L(1)+L(2)+L(3)
      DO 37 I=1,NS
      L1=L(I+99)
      J=L(I+50)
      J2=J+1
      J3=J2+1
      GO TO(35,34,36),LI
C     TO 108--, SHAFTS OF MG SETS.
C     TO 105--, COMPUTE THE TORQUES OF THE GENERATORS.
   34 J9=J+8
      J10=J+9
      J11=J+10
      B(33,I)=(A(34,I)*(Y(J9+3)-B(35,I))+A(35,I)*Y(J9+4))*(
     1 Y(J9)*B(50,I)+Y(J10)*B(54,I)+Y(J11)*B(52,I))+A(36,I)*Y(J9+5)*
     2(Y(J9)*B(49,I)+Y(J10)*B(53,I)+Y(J11)*B(51,I))
      IF(A(33,I).LE.0.0) GO TO 105
      B(33,I)=B(33,I)-A(33,I)*(B(56,I)*(Y(J9)*Y(J9)+2.0*Y(J10)*Y(J11))
     1+B(58,I)*(Y(J10)*Y(J10)+2.0*Y(J9)*Y(J11))+B(60,I)*(Y(J11)*Y(J11)
     2+2.0*Y(J9)*Y(J10)))
  105 B(33,I)=-0.737564*A(15,I)*B(33,I)
C     TO 107--, COMPUTE THE TORQUES OF THE MOTORS.
      B(3,I)=(A(4,I)*(Y(J+3)-B(7,I))+A(5,I)*Y(J+4))*(Y(J)*B(20,I)+Y(J2)*
     1B(24,I)+Y(J3)*B(22,I))+A(6,I)*Y(J+5)*(Y(J)*B(19,I)+Y(J2)*B(23,I)+Y
     2(J3)*B(21,I))
      IF(A(3,I)) 107,107,106
  106 B(3,I)=B(3,I)-A(3,I)*(B(26,I)*(Y(J)*Y(J)+2.0*Y(J3)*Y(J2))+B(28,I)*
     1(Y(J2)*Y(J2)+2.0*Y(J)*Y(J3))+B(30,I)*(Y(J3)*Y(J3)+2.0*Y(J)*Y(J2)))
  107 B(3,I)=0.737564*A(15,I)*B(3,I)
  108 F(J+7)=32.174*(B(3,I)-B(33,I))/A(26,I)
      F(J9+6)=B(5,I)
   35 F(J+6)=B(5,I)
      GO TO 37
C     TO 39--, SHAFTS OF INDUCTION MOTORS.
C     TO 38--, COMPUTE THE EM TORQUES OF THE INDUCTION MOTORS.
   36 B(3,I)=A(4,I)*Y(J+3)*(Y(J)*B(20,I)+Y(J2)*B(24,I)+Y(J3)*B(22,I))+A(
     14,I)*Y(J+4)*(Y(J)*B(19,I)+Y(J2)*B(23,I)+Y(J3)*B(21,I))
   38 B(3,I)=0.737564*A(7,I)*B(3,I)
   39 F(J+6)=32.174*(B(3,I)-B(12,I))/A(9,I)
      F(J+5)=B(5,I)
   37 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TORIM
C     COMPUTE THE MECHANICAL TORQUES OF THE INDUCTION MOTORS FROM GIVEN
C     SPEED/TORQUE TABLES BY LINEAR INTERPOLATION.
C     THE END VALUES OF TORQUE ARE USED WHEN THE SPEED FALLS OUTSIDE THE
C     RANGE OF A TABLE, AND A COMMENT IS WRITTEN IN TAPE 6.
      COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
     1,LP1,LP2,LP3,TITLE,HEAD
      DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(5
     10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),
     2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)
     3,LP2(50),LP3(50),TITLE(39),HEAD(39)
  900 FORMAT(//35H ***SPEED OF INDUCTION MOTOR NUMBER,I3,34H IS LARGER T
     1HAN VALUES IN TABLE***/7H SPEED=,E12.5/15H TORQUE SET TO ,E12.5//)
  901 FORMAT(//35H ***SPEED OF INDUCTION MOTOR NUMBER,I3,35H IS SMALLER
     1THAN VALUES IN TABLE***/7H SPEED=,E12.5/15H TORQUE SET TO ,E12.5//
     2)
      N1=L(1)+L(2)+1
      N2=N1+L(3)-1
      DO 100 I=N1,N2
      J = L(I+50)+6
      IF (Y(J).LT.A(11,I))  GO TO 90
      NN= A(10,I) -1.0
      DO 10 K=1,NN
      KK = 11+2*K
      IF (Y(J).LT.A(KK,I)) GO TO 20
   10 CONTINUE
      B(12,I) = A(KK+1,I)
      N=I+1-N1
      WRITE (6,900) N,Y(J),B(12,I)
      GO TO 100
   20 KK = K*2+9
      B(12,I) = A(KK+1,I)-(((A(KK+1,I)-A(KK+3,I))/(A(KK,I)-A(KK+2,I)))*
     1 (A(KK,I)-Y(J)))
      GO TO 100
   90 B(12,I) = A(12,I)
      N=I+1-N1
      WRITE (6,901)N,Y(J), B(12,I)
  100 CONTINUE
      RETURN
      END
```